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Measurement of Air Currents; Pilot Balloon Method

(Chapter 2 of the Book 'Aerology')

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CHAPTER II

MEASUREMENT OF AIR CURRENTS. PILOT BALLOON METHOD

Two principles are the basis for measuring air currents in the free atmosphere. The first of them is based on the observation of movements of certain objects freely affected by air currents, and therefore containing their velocity. As a basis for the second is the pressure of an air current on a body as related to the velocity of the air movement.

Clouds formed at various altitudes, artificial smoke and meteor trails may serve as indicators of air currents according to the first principle. Determining the velocity and direction of their movement, the velocity and direction of the wind is found at those altitudes on which they are located. However, such forms of observation are related to the existence of these respective formations and, as a rule, provide a means of determining the wind only at the level of their formation. Therefore, the application of special indicators of the type of free aerostats (spherical aerostat, pilot balloon, sounding balloon, radiosone apparatus) has been found to be more practical. Their advantages are included in that following air currents, they at the same time ascend and permit the measurement of the velocity and direction of the wind while passing through the various layers of the atmosphere.

In this manner, in measurements according to the first principle, natural and special indicators serve as floats carried by the velocity and in the direction of air currents.

In measurements according to the second principle it is necessary to carry the instrument provided with this or that air measuring device to a certain altitude, using a captive method of sounding (kite, captive aerostat), i.e., so that at each level the air moves in relation to the instrument which remains practically motionless. According to the degree of reaction of the air current upon the instrument, for example, on the speed of rotation of the anemometer, the velocity of the air is determined.

The application of the first principle through the use of pilot balloons, radiosone apparatus, sounding balloons, permits the measurement of the mean air velocity in a certain layer. The application of the second principle permits the measurement of air at a certain level, determining either its mean velocity for a given time interval, or its momentary values (wind pulsations).

The simplest and most applied method in contemporary aerological practice is pilot balloon observation based on the first principle. Most recently the method of radio balloon observations has been developed and applied. It has that advantage that the measurement of velocity and wind direction may be conducted in the absence of visibility (in fog, in clouds, at night).

This chapter is devoted to a detailed investigation of the basic method - pilot balloon observations. Other methods of wind measurement are described in chapters on the captive methods of sounding and the application of radar devices.

A. PILOT BALLOON OBSERVATIONS FROM ONE POINT

1. Basic Conditions of Pilot Balloon Method

The pilot balloon consists of a rubber casing filled with hydrogen so that it contains a certain lifting force. Released for free flight such a balloon ascends and at the same time is displaced horizontally through the action of the wind. Thanks to the small mass of the balloon, its movement responds to the air currents practically without inertia. The ascending pilot balloon therefore permits the measurement of the velocity and direction of the wind in all layers passed by it. According to the positions of the pilot balloon at certain time intervals, it is easy to determine its mean horizontal displacement, and from this the mean velocity and the wind direction for the corresponding atmospheric layers are found.

As was already stated, the position of the pilot balloon may be determined by various methods. In usual pilot balloon observations with the aid of one or two theodolites, the horizontal (azimuths) and vertical angles at which the balloon is observed are obtained; and then the projection of the path of the balloon is plotted geometrically and its horizontal displacements for various intervals of time are obtained.

[diagram page 23]

Figure 1. Pilot balloon triangle

On Figure 1, the point of observation is at point O, P denotes the position of the pilot balloon at a certain moment of time, C its projection on a horizontal plane, PC = H its altitude, δ the vertical angle, α the azimuth and r the inclined distance.

For the solution of the triangle OPC thus constructed, one of its sides must be known. By an observation from one point (one theodolite), the altitude of the balloon is assumed which, as we shall see, is determined theoretically. By observations from two points the altitudes are computed trigonometrically.

In radio pilot balloon observations the coordinates of the balloon are determined with the aid of radar or radio direction finders. By the first method of observing radio pilot balloons the vertical angle, the azimuth and inclined distance are measured. If the object of observation is a radiosonde, then, in addition to the three mentioned coordinates, the altitude of the radiosonde is determined by the pressure signals. In radio direction finding, the vertical angle and the azimuth are measured; the determination of altitude is done by the pressure signals broadcast by the radiosonde or the radio pilot balloon provided with a pressure recorder.

Table 1 shows which balloon coordinates are measured in this or that method.

TABLE 1 PAGE 24

Method of observation		Coordinates measured: altitude	azimuth	vertical angle	inclined distance
Pilot balloon method	(1) from one point	-	+	+	-
	(2) from two points	-	++	++	-
Radio pilot balloon Method	(1) radar				
	(a) radio pilot balloon	-	+	+	+
	(b) radio-sonde	+	+	+	+
	(2) radio direction finder	+	+	+	-

If the altitude, azimuth and the vertical angle of the pilot balloon are determined as a function of time from the moment of release, it is possible to compute its trajectory in space and the horizontal velocity, i.e. the velocity of the wind, at various altitudes according to the following method. One of the articles of N. Ye. Zhukovskiy refers to this. Assuming the origin of spherical coordinates at the point of release of the pilot balloon, at point O (Figure 2), we can state

[formulas page 24] (1)

Cancelling r with the aid of the expression for z, we obtain [formulas page 24] (2)

Formulas (2) give the position of the projection of the pilot balloon on a horizontal plane. Taking the derivative with respect to time for x and y, we will obtain the component velocities of the pilot balloon in a horizontal plane, i.e., the component velocities and direction of wind at various altitudes:

[formulas page 25] (3)

Substituting $\frac{d\delta}{dt}$ and $\frac{d\alpha}{dt}$ by the relation of limiting differences $\frac{\Delta\delta}{\Delta t}$ and $\frac{\Delta\alpha}{\Delta t}$, taken from the measurements of δ and α by the theodolite, and assuming the known or computed vertical velocity of the pilot balloon to be $\frac{dz}{dt}$, we have the possibility, according to the above stated formula, to compute the components of wind velocities $\frac{dx}{dt}$ and $\frac{dy}{dt}$ with certain approximations.

The computation of components of wind velocity with the aid of formula (3) presents considerable difficulties, and, therefore, in the practice of pilot balloon and radio pilot balloon observations, a simplified method of computing the velocity and direction of wind is used. For this a horizontal projection of the trajectory of the pilot balloon is constructed using the system of polar coordinates (Figure 1): the

[diagram page 25]

Figure 2. Projection of the pilot balloon on a horizontal plane in the system of spherical coordinates.

distance from the start of the coordinates to the projection of the balloon OC and the azimuth α . It is easy to see that $OC = H \operatorname{ctg} \delta$, where H is the altitude of the balloon and δ is the vertical angle (angle of the location). The horizontal distance of the pilot balloon OC thus found and its azimuth α , i.e., the horizontal angle of balloon direction, determine the position of the projection of the balloon C.

Let (Figure 3) points P_1, P_2, P_3, P_4. . . represent the position of the pilot balloon for successive moments of time, for example, through 1, 2, 3, 4 minutes, etc. after the release of the balloon from point O. The position of the projections of the balloon on a horizontal plane for these same moments is represented by points C_1, C_2, C_3, C_4. . . As was stated, the position of each of the projections is determined along a corresponding horizontal distance of the balloon and its azimuth. The broken line $C_1C_2C_3C_4$. . . represents the horizontal projection of the path of the pilot balloon. Each of the segments OC_1, C_1C_2, C_2C_3, C_3C_4 . . . represents that distance along which the pilot balloon is displaced by the wind along the horizontal during one minute in atmospheric layers: $(0 - H_1)$, $(H_1 - H_2)$, $(H_2 - H_3)$, $(H_3 - H_4)$ . . . The value of the wind velocity in meters per second or kilometers per hour may be obtained through the measurement of the length of each of the segments, relating them to the selected unit of time. The direction of the wind is obtained by way of determining the angles between north and the segments.

From the arguments presented it is evident that the values of velocity and the wind direction obtained characterize the mean velocities and direction in the layer determined by the altitude of the balloon at the start and finish of the time interval. Therefore, it is generally accepted to relate the data obtained to the altitude corresponding to the center of the layer: $\frac{H_n + H_n + 1}{2}$, where H_n is the altitude at the start and $H_n + 1$, the altitude at the finish of the time interval.

The altitude of the pilot balloon may be obtained if its vertical velocity, i.e., the velocity of the displacement of the vertical determined by its free lifting force, is known. In the method of pilot balloon observations from one point the vertical velocity is taken as constant. Then the altitude of the balloon H for any moment of time is obtained by the formula

[formula page 26] (4)

where W is the vertical velocity of the pilot balloon, and t the time elapsed since the moment of release.

[diagram page 26]

Figure 3. The path of the pilot balloon and the projection of its path on a horizontal plane.

In base (from two points) pilot balloon observations the vertical velocity is determined by computation trigonometrically for balloon altitudes at certain moments of time. In radio pilot observations, trigonometric computations are used to obtain these results, or the vertical velocity may be computed by the values of altitudes obtained from pressure readings.

The given altitudes, as well as the values of the vertical angles obtained during observations and the azimuth of the balloons permit the processing of the observations according to the above stated principle, i.e., to determine the velocity and the direction of the wind at various altitudes. The most widely used method is the graphic method of processing. It is distinguished by simplicity with a sufficient degree of accuracy and shows a considerable saving in time in comparison with the analytic method.

2. Full and Free Lifting Force of the Pilot Balloon

At the present time casings of pilot balloons are prepared from elastic rubber capable of great expansion. During ascent of the balloon, with a decrease of outside pressure and expansion of the hydrogen contained inside, such a casing freely expands and the volume of the balloon increases.

In accordance with the law of Archimedes, a force directed upward acts on the pilot balloon. It is determined by the difference between the weight of air and hydrogen (or other gas) within the pilot balloon and is called the full lifting force. If V represents the volume of the balloon, ρ the weight of 1 cubic meter of air, and γ the weight of hydrogen (in the future the values ρ and γ will be called density of air and hydrogen, and the values $\frac{\rho}{g}$ and $\frac{\gamma}{g}$, their mass density (g is the acceleration of gravity)), then the full lifting force of the balloon E will be

[formula page 27] (5)

The full lifting force related to a unit of volume, i.e., 1 cubic meter, is called the specific lifting force of gas and represents:

[formula page 27]

However, the ascent of the pilot balloon and its vertical velocity depend not on the size of E, but on its free lifting force A, differing from E by the magnitude of the load of the balloon. The latter is determined first of all by the weight of the casing and by the additional load lifted by the balloon (instrument, lantern, etc). In the simplest case, only the weight of the casing B is considered; then

[formula page 27]; (6)

A and B are usually expressed in grams, V in cubic meters, and ρ and γ in grams per cubic meter.

For initial conditions, the expression (6) is stated in the form

[formula page 27] (7)

Let us find the relation A_o and A for any altitude.

According to data from experiments for normally filled balloons, the difference in pressure inside the balloon and the external pressure resulting from the resisting forces of the casing, represents only several millimeters of the mercury column and remains nearly constant up to the bursting of the casing. With the increase of the initial dimensions of the casings the difference in the pressure is therefore diminished. In any case, the pressure of gas inside the balloon may be considered, in value, close to the pressure of the surrounding air.

Let us assume further, that during the entire time of ascent of the balloon the temperature of the gas is equal to the temperature of the surrounding air, and the amount of gas in the casing does not change. As is known, a change in the density of the gas or its weight per cubic meter depends on a change in its pressure and temperature. From the above it follows that the change in the density of the hydrogen during the ascent of the balloon follows the same pattern as the change in density of the surrounding air. Inasmuch as the volume of the balloon varies inversely in proportion to the density of the gas, we have

[formula page 27] (8)

from which

[formula page 28] (9)

and

[formula page 28] (10)

Consequently, $A = A_0 = \text{const}$, i.e., the free lifting force at the time of ascent of the pilot balloon remains constant.

It is necessary, however, to remember that this conclusion is obtained on the assumption of the equality of temperatures of the gas in the balloon and the surrounding air and with the absence of gas diffusion through the casing. The temperature of the pilot balloon equals the temperature of the surrounding air sufficiently quickly thanks to the small mass of the gas in the casing. Diffusion of the gas diminishes the lifting force of the balloon, however, as experience has shown, during the usual interval of time of observation the loss of hydrogen does not attain a volume which could noticeably affect the lifting force.

3. The Vertical Velocity of the Pilot Balloon

After release, under the influence of the free lifting force, the balloon begins to ascend with a certain acceleration. On the other hand, from the very beginning of its movement upward, the resisting force of the air directed against the free lifting force appears. The resisting force increases proportionately to the square of the velocity, and after a few seconds becomes equal to the free lifting force. From this moment the movement of the balloon upward occurs under the resulting vertical velocity.

On the basis of experiments in aerodynamic tunnels, for a balloon with a velocity not over several dozen meters per second, the value of the resistance R may be expressed with the aid of the following formula:

[formula page 28] (11)

where c is the numerical coefficient, $S = \frac{\pi D^2}{4}$ is the area of the great circle of the balloon (D is the diameter of the balloon), $\sigma = \frac{\rho}{g}$ is the mass density of the air (g is the acceleration of gravity force), W is the vertical velocity of the pilot balloon.

Including in the above stated expression (11) the values D and ρ, we obtain:

[formula page 28], (12)

where $K = \frac{c\pi}{4g}$.

The constancy of the movement of the balloon from the moment of its release may be stated in the form [formula page 28], (13)

where m is the mass of the casing and hydrogen and $\frac{dW}{dt}$ is the acceleration of the balloon in the vertical.

Substituting R in the above obtained expression (12) we can state

[formula page 29]

or

[formula page 29],

where $\frac{dz}{dt} = W$.

From which it follows that

[formula page 29]

of

[formula page 29]. (14)

Substituting W^2 with y, we restate the equation obtained in the form

[formula page 29].

Integrating this equation, we shall obtain the following expression for y:

[formula page 29]

or

[formula page 29].

Making the contraction and substituting y for W^2, we obtain

[formula page 29]. (15)

Expression (15) first of all shows that in the first moments the balloon is displaced with a positive acceleration, inasmuch as with the increase of z the value $e^{-\frac{2ke}{m}D^2 z}$ diminishes and the radicand increases, approaching unity. For the evaluation of the effect of value $e^{-\frac{2ke}{m}D^2 z}$ on the determination of W, let us establish the value of z, whereupon this value becomes, for example, equal to 0.01, i.e., the condition

[formula page 30]

is satisfied.

Because, in this,

[formula page 30],

from which

[formula page 30],

and

[formula page 30].

Substituting in this expression the values of magnitudes corresponding to a normally filled casing No 20, if its weight and hydrogen amount to 60 grams, and the diameter of the balloon is 65 centimeters, and taking ρ = 0.0013 x 981 g/cm^{2}sec^2, and k = 0.0003 sec^2/cm, we shall obtain z = 1 m for the above conditions. In this manner, the difference between the limiting value W and its value when $z \approx 1$ m becomes equal to 0.01W. This permits us to consider that from the moment of release of the balloon, its vertical velocity is determined by the formula

[Formula page 30] (16)

We arrive at the same conclusion using expression (12) and taking R = A in it. This states that the condition of the vertical velocity practically ensues from the moment of the release of the balloon.

In this manner, the value of the vertical velocity of the balloon depends on its free lifting force, its diameter and the weight of 1 cubic meter of air. As can be seen in formula (16), the coefficient k is the magnitude, whose value is related to coefficient c. Coefficient c, in general, is not constant and is determined by the value of Reynolds' number:

[formula page 30],

where η is the coefficient of dynamic viscocity of the air.

Experiments in the study of air resistance produced by a body moving in it have shown that c remains constant only in the case when the value Re becomes greater than one and less than another definite value, and in the interval between them does not change. Besides, in turbulent air, the value c, corresponding to the same values of Re for still air appears less, which at other similar conditions calls forth an increase in the vertical velocity. We shall return somewhat later to the question on the actual conditions of movement of the balloon in connection with the changes of conditions of resistance.

Returning to formula (16) and expressing the diameter of the balloon through the length of its circumference, we obtain

[formula page 31]

or

[formula page 31], (17)

where C is the length of the circumference, $a = \frac{\pi}{\sqrt{k}}$.

In this case the vertical velocity is determined in relation to the free lifting force and the length of the circumference. Values A and C are determined by direct measurement. Value a is taken from tables, and value ρ may be obtained according to the data of measurement of pressure and the temperature of the air.

4. Determination of the Vertical Velocity of the Pilot Balloon According to the Free Lifting Force and Weight of the Casing

The vertical velocity of the pilot balloon may be determined by its free lifting force A and the weight of the casing B.

The free lifting force of the balloon may be expressed in the form

[formula page 31]

where C is the length of the circumference, and consequently $\frac{C^3}{6\pi^2}$ is the volume of the balloon.

As we have seen, the full lifting force may be represented as the sum of the free lifting force A and the weight of the casing B.

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In this manner, we can state

[formula page 31] (18)

from where

[formula page 31]

Referring to formula (17) and substituting the obtained expression for C, we shall have

[formula page 31]

or

[formula page 32] (19)

It is evident that b is a certain coefficient depending on a and n.

5. Variation in the Vertical Velocity of the Pilot Balloon with Altitude in Relation to the Variation in the Density of the Air

Let us clarify the effect of changes in its determining factors under the condition of stationary [constant?] movement upon the vertical velocity W of the ascending balloon.

For initial conditions, let us state the expression for vertical velocity as follows:

[formula page 32] (20)

Let us study the relation of W to W_o:

[formula page 32]

As was pointed out earlier, the free lifting force remains constant, i.e., $A = A_o$, the length of the circumference C increases with altitude and the density of the air ρ decreases. The change in the circumference of the balloon is proportional to the cube root of the change of its volume, i.e.,

[formula page 32]

or, in accordance with conditions $\frac{V}{V_o} = \text{---}$,

[formula page 32] (21)

Considering that the coefficient a does not vary with altitude, i.e., $a = a_o$, we obtain

[formula page 32]

The first multiplier of the right portion characterizes the decrease of the vertical velocity caused by the increase in the volume of the balloon and, therefore, by the increase in the air resistance, and the second multiplier characterizes the increase in the vertical velocity caused by the decrease in the density of the air which results in a decrease in resistance.

The expression obtained may be stated in the form

[formula page 32] (22)

In this manner, the vertical velocity of the ascending balloon must change inversely proportional to the root to the sixth power of the change in the weight of 1 cubic meter (or density) of the surrounding air, i.e., the vertical velocity must increase with altitude.

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On the basis of aerological sounding data in the middle latitudes, a mean numerical value for the relation $\left(\frac{\rho_0}{\rho}\right)^{\frac{1}{6}}$ may be obtained, where ρ_0 is the mean annual density on the ground, and ρ is the mean annual density of the air at various altitudes. On the basis of these values, Table 2, showing the theoretical changes in the vertical velocity in relation to the initial velocity at the ground in dependence with the changes of density with altitude, is constructed.

Table 2

Theoretical Changes in the Vertical Velocity of Pilot Balloons with Altitude

Altitude (in km)	. . .
$\frac{W}{W_0}$	. . .

From Table 2 it is evident that the theoretical increase of the vertical velocity of the pilot balloon with altitude occurs very slowly, and only at about an altitude of 5 km does it amount to 10 percent of the initial velocity.

The inescapable loss of gas as a result of diffusion brings about a certain diminishing to the vertical velocity with altitude, and even though the value of this effect can be appraised with difficulty, the diffusion partly compensates the increase in velocity in connection with the change in the density.

Taking into consideration that the method of pilot balloon observations from one point may not give a great degree of accuracy to the measurement of the velocity of the wind (see No 27), it is permissible to ignore the effect of the change in the density of air with altitude on the vertical velocity of the pilot balloon.

6. The Effect of Differences in Temperature of Hydrogen and the Surrounding Air on the Change in Vertical Velocity

In the solution of formula (22) it was assumed that during the ascent of the balloon, the temperature of the gas was equal to the temperature of the surrounding air. If, however, this condition is not met, then taking into account the effect of the difference of temperatures of hydrogen in the balloon and the surrounding air results in the following expression for the change in the vertical velocity:

[formula page 33] (23)

where T and T' are absolute values of the air and hydrogen temperatures at a certain altitude, and m is the weight of the casing and the hydrogen filling the balloon. Formula (23) shows that a change in the vertical velocity in the first place increases with an increase in the difference of temperatures and depends on its sign inasmuch as at $T > T'$ the vertical velocity diminishes and vice versa. In the second place, the greater the value of the relation $\frac{m}{A_0}$, the greater is the change in W, i.e., other conditions being equal except for a more heavily loaded balloon.

If we take loaded and unloaded balloons, then, in order to obtain equal vertical velocities, the loaded balloon must be filled to a greater capacity than the unloaded one, and consequently, the effect of the differences in temperature upon it will be felt more greatly. With equal balloon volumes, the effect of temperature differences is reflected more in the movement of the loaded balloon which has a smaller free lifting force.

Inasmuch as the relation $\frac{m}{A_0}$ for pilot balloons is usually less than 1/3, the effect of temperature differences for them is not great. This difference arises more frequently during the passage of the balloon through layers of temperature inversions. The increase in the difference of temperatures of hydrogen and the surrounding air in this case brings about an inconsequential variation in the vertical velocity of pilot balloons and more important variations in the vertical velocity of radio sounding apparatus, sounding balloons, etc.

7. Methods for the Practical Determination of the Vertical Velocity

The practical determination of the vertical velocity is done with the aid of tables, graphs, nomograms and special slide rules constructed on the basis of formulas (17) and (19).

Let us take formulat $W = \frac{a\sqrt{A}}{C\sqrt{p}}$, determining the vertical velocity as a function of free lifting force A and the length of the circumference C, and make certain transformations. Let us multiply and divide the first portion of the formula by $\sqrt{p_0}$, where p_0 is a certain standard density of the air, namely, at a temperature of 20 degrees and a pressure of 760 millimeters. Then

[formula page 34]

Specifying $\frac{a}{\sqrt{\rho_0}}$ through d, we obtain

[formula page 34] .

Formula (24) is used as a basis for two tables, by means of which the vertical velocity is determined.

In the first table (appendix 1) the values of W are given computed on the assumption of the standard density of air, when $\rho = \rho_0 = 1.205$ kg/m^3.

In this case

[formula page 34]

The value of the vertical velocity W_0 is therefore expressed in meters per minute, the value of the free lifting force A in grams, and the length of the circumference C in centimeters.

As was stated, the coefficient of resistance c remains constant only at Re above or below its definite values, and in the interval between them c varies. Experiments have shown that near the surface of the ground the path of variation of Re, upon which c depends, is nearly parallel to the path of variation of A. Hence it appears possible to take into account the non-constancy of c, determining it in relation to A.

It must be remembered that the coefficient d is obtained as a result of a series of transformations and related to coefficients a, k and, finally, c.

Table 3 shows the values of d for various values of A under

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conditions where A, C, and W_o are expressed in the above stated units of measurement.

Table 3

Values of Coefficient d for Various Values of the Free Lifting Force A

A ...

d ...

For values of A less than 140 grams, the coefficient d is accepted as constant and equal to 3,110, for values of A more than 240 grams, d is taken as equal to 3,650.

Inasmuch as the actual value of the density of the air at the moment of release of the pilot balloon is in general different from the standard for which the first table was computed, the values for vertical velocities obtained through it require a correction. This correction is taken into account by formula (24) in the form of a multiplier $\sqrt{\frac{\rho}{\rho_o}}$. The value of the magnitude of the correction multiplier on the air density is found with the aid of a second table (appendix 2) where the magnitude $\sqrt{\frac{\rho}{\rho_o}}$ is computed for various values of pressure p and temperature t, where ρ is the density of the air at the moment of observation.

By the multiplication with the value of vertical velocity found according to the first table the final corrected value of the vertical velocity W is found.

For cases where A and C are expressed by interval values, it is necessary to interpolate when obtaining them.

In addition to tables for the determination of vertical velocity, nomograms and slide rules may also be used.

Figure 4 shows one of these rules (its face side), the pilot balloon ~~ruler~~ of V. A. Ambartsumov, in the upper part of the ~~ruler~~ there is a cut, on whose lower edge a scale of the length of the circumference in centimeters is inscribed. Along the length of the cut moves a slide, provided with a scale of the free lifting force in grams. Upon the movement of the scale A, an index in the form of an arrow, located in the lower portion of the slide,moves along the central cut of the slide rule and slides along the constant scale of vertical velocities. For the determination of the uncorrected vertical velocity, it is necessary to align the division corresponding to A, on the upper movable scale, with the division corresponding to C on the lower constant scale. Then the index will show the sought value for the uncorrected vertical velocity. For the determination of the corrected vertical velocity the lower slide is so set that in the lower right opening the division inscribed on the slide of the scale corresponding to the temperature measured is set opposite the division corresponding to the pressure on the constant scale. Then, opposite the index established on the scale of the uncorrected vertical velocity, the division of the upper scale of the lower slide will appear corresponding to the corrected vertical velocity.

Tables have also been compiled for the determination of the vertical velocity of the pilot balloon according to the formula (19).

Whereupon, the density of the air ρ_0 is taken as constant (at 0 degrees and 760 millimeters). For the actual value of the initial air density ρ, the table vertical velocity must be corrected by the multiplier $\left(\frac{\rho_0}{\rho}\right)^{\frac{1}{6}}$. This is evident from formulas:

[formula page 36] ,

or

[formula page 36]. (25)

The mgnitude of the correction multiplier $\left(\frac{\rho_0}{\rho}\right)^{\frac{1}{6}}$ for various values of pressure and air temperature near the ground differs little

Figure 4 - Slide Rule [page 36]

Lifting Force A

Circumference length C cm

Table vertical velocity W' m/min

Corrected vertical velocity W m/min

SLIDE COMPUTING

PILOT BALLOON TABLE

Correction for air density — Pressure B mb; Temperature T 0 degrees; Pressure P mm

Figure 4. General view of the pilot balloon slide rule of Ambartsumov.

from unity. Therefore, in the determination of the vertical velocity according to A and B, the correction multiplier is not taken into account. As far as coefficient b_1 is concerned, it should be remembered that in the solution of formula (19) we used the coefficient of proportionality n, which is related to the value of the specific lifting force of hydrogen. However, the effect of a difference in the density of the hydrogen used is very small. Therefore, practically, we may consider that coefficient b_1 varies only in relation to the free lifting force, similarly to that which took place in Table 3.

For the density of commercial hydrogen = 0.121 kg/m^3 at a temperature of 20 degrees and pressure of 760 millimeters, the value of b_1 is shown in Table 4, considering that A and B are expressed in grams and W in meters per minute.

Table 4

Values of Coefficient b_1 in relation to the Free LiftingForce A

A.....

b_1....

To obtain the vertical velocity according to the free lifting force A and the weight of the casing B, a graph of isopleths may also be constructed on which the values B are shown along a horizontal axis and the values of A in grams are represented along the vertical. The isolpleths will represent a series of curves of vertical velocities depending on the changing parameters A and B. Figure 5 shows such a graph. Formula (25) may be stated generally in the form:

[formula page 37] (26)

where x and y are the indicators which some authors prefer to find empirically, for example, on the basis of the determination of the vertical velocity according to base pilot balloon observations. Also the values for coefficient b_1 are sometimes determined through an experimental method, considering them to be constant for the weight of the casings and the degree of their filling within certain definite intervals

[figure 5 - page 37]

grams

m/min

free
lifting
force

vertical
velocity

weight of casing

Figure 5. Graph for the determination of the vertical velocity of the pilot balloon according totthe weight of the casing and the free lifting force.

8. Standard Vertical Velocity of Pilot Balloons

If the vertical velocity of the pilot balloon is expressed by a rounded off number, for example, 100 or 200 meters per minute, then during processing of pilot balloon observations a considerable saving in time is achieved in computations and the accuracy of plotting of the projections on Molchanov's circle is increased. In addition, for such standard vertical velocities it is more convenient to obtain corrections to tabular values for the precision of one-point observations.

For the pilot balloon to ascend with a definite vertical velocity, it must have certain dimensions depending on the wight of the casing B. These dimensions, i. e., the norm for filling the casings in order t obtain a definite value for W, can be found in several ways.

Let us suppose that the density of hydrogen which is used to fill the pilot balloon is known. As we have previously seen it is permissible for the density of hydrogen in the balloon to vary proportional to the density of the air, i. e., $\frac{\gamma}{\gamma_0} = \frac{\rho}{\rho_0}$ where γ_0 and ρ_0 are the density of hydrogen and air under standard conditions, and γ and ρ , under actual conditions. Then the expression for the full lifting force

[formula page 38]

may be stated in the form:

[formula page 38]

or, including the length of the circumference C,

[formula page 38]. (27)

On the other hand

[formula page 38] (28)

Equation (27) and (28) may be solved in relation to A and C, if W is to be found. Actually, the value ($\rho_0 - \gamma_0$), i.e., the specific lifting force of hydrogen, under normal conditions has a definite value, while the weight of casing b may be measured. The ratio $\frac{\rho_0}{\rho}$ is determined in relation to the values of pressure and temperature of the air at the moment of filling the balloon, and d is known fromthe tables.

For the solution of the two equations (27) and (28), a nomogram (Figure 6 and 7) may be constructed. The nomograms shown are computed for γ_0 = 125 grams per cubic meter and at 0 degrees and pressure of 760 millimeters.

By means of the first nomogram, the value $\sqrt{\frac{\rho_0}{\rho}}$, expressed by the amount of deviation of the density of the air from the normal, i.e., $\Delta\rho$ in percent, is obtained. For this (Figure 6), a ruler is applied in such a manner that its edge passes through the divisions of the temperature t and pressure p scales corresponding to the observed values. The intersection of the edge of the ruler with the center scale will give the sought value for $\Delta\rho$.

Then on the second nomogram (Figure 7) the ruler is placed in such a manner that its edge passes through the division of scale B corresponding to the weight of the casing and through the earlier found value of $\Delta\rho$. Then the intersection of the same edge of the ruler with scales A and C will give the sought values for A and C, determining the norm for filling the casing in order to obtain the selected vertical velocity.

In filling the balloon up to the value for A (C) found through the nomogram, the density of the hydrogen is checked on whether it corresponds to that computed by using the measured factual value of C (A) and the one found according to the nomogram. In an affirmative case, the factual C (A) must coincide with that found by the nomogram. A deviation of the measured circumference from that obtained by the nomogram of not more than, for example 2 percent, will show that the vertical velocity will deviate from the one sought also by not more than 2 percent

[diagram page 39]

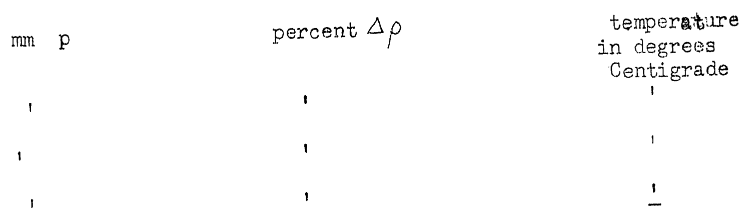

Figure 6. Nomogram for the determination of deviation of the air density from the normal.

A more general solution for the filling of the pilot balloon in order to obtain a given vertical velocity in case the density of the hydrogen is unknown is possible. Let us look at the method suggested by A. V. Mikhaylovskiy. Let us assume that the pilot balloon is filled to some value of free lifting force A_1 and its circumference was found equal to $C_1 = \pi D_1$. Then, for these conditions we can state

[formula page 39]- (29)

Let values A and C correspond to conditions when the balloon is filled for the achievement of the required velocity W. Analogically to the above mentioned equality, we can state

[formula page 39]. (30)

Taking the relation of equation (30) to (29) and replacing the relation of diameters by the relation of circumferences, we obtain

[formula page 40].

[diagram page 40]

Δp A B C

Figure 7. Nomogram for the determination of degree of filling the baloon for a given vertical velocity.

Besides, it is known to us that

[formula page 40]. (31)

Determining C from the foregoing equation and substituting it in the expression for W, we obtain [formula page 40]. (32)

Knowing A_1, C_1, B and the density of the air ρ, it is possible to find A for the given value of W. The determination of A may also be done withthe aid of a nomogram.

The nomograms are computed for A_1 = 180 grams. Initially the pilot balloon is filled up to A_1 = 180 grams and the circumference C_1 is measured, then, taking into consideration the deviation of the air density from the normal and the weight of the casing B, the value of A corresponding to the standard vertical velocity sought is found by means of the nomogram.

I. Ya. Tanatar gave a method for the compiling of tables for the computation of filling up for the standard vertical velocity. In these tables, for each weight of casing B, with various values of density of air and hydrogen, the amounts of free lifting force A and the lengths of the circumference C, corresponding to W equal 100, 200, and 300 meters per minute, are shown. Consequently, this method presupposed that the density of hydrogen is known.

9. Aerological Theodolites and Main Requirements for their Construction

For the measurement of azimuths and vertical angles of direction of pilot balloons, thus determining at a known altitude the position of the balloon in space, aerological theodolites are used. They differ from theodolites used for other purposes.

Let us delve into the requirements needed for aerological theodolites.

Nearly all aerological theodolites have a broken telescope, permitting the convenient and unhindered observation of the balloon in any position, not excluding that in which the balloon is located in the zenith or nearly so. With such an arrangement in any position of the objective the ocular part of the telescope and the eye of the observer is located at one and the same horizontal plane.

In every aerological theodolite the possibility for a sufficiently quick reading of the measurements must be provided, so that with fast movements of the pilot balloon the latter will not leave the field of vision of the telescope during the time necessary to make the reading.

For the first moment of observation after the release of the balloon, it is very important to be able to make considerable sweeps with the telescope in a vertical as well as in a horizontal plane, with the possibility of later switching to slow sweeps.

The accuracy in measuring angles in the theodolites generally used is 0.1 degrees. In making pilot balloon observations from one point to great altitudes as well as when making base observations theodolites with a higher accuracy, to 1 degree or 0.01 degree [correction page changes 1degree to 1 minute] should be used.

The optical system of the aerological theodolite should have adequate magnification, good lighting and large field of vision. The filling of these requirements will permit making of observations without great difficulties during the first moments after the release of the balloon, when it is at a great distance, and under night conditions.

Inasmuch as the determination of azimuths requires the orientation of the theodolite according to the cardinal points, many systems of theodolites are equipped with compasses.

Furthermore, the construction of the theodolite must ensure the possibility of convenient operation at night. For this a system for lighting of the field of vision of the telescope and the indexes of the indicators for the measurement along the horizontal circles is provided.

Finally, the simplicity and the stability of construction of theodolites must satisfy the conditions of field work.

10. Basic parts of the Aerological Theodolite and the Arrangement of the Telescope Optical System

In order to fix any position of the pilot balloon, the optical axis of the telescope of the aerological theodolite must be movable. For this the union of the axes of rotation of the theodolite must satisfy conditions in which the optical axis 1 (Figure 8), being perpendicular to the horizontal axis 2, will be able to rotate in a vertical plane, and the horizontal axis will be able to rotate around vertical axis 3. Then the optical axis may rotate around the horizontal and vertical axes and be directed toward any point.

[diag

[diagram page 42]

Figure 8. Diagram of coupling of axes and circles of the theodolite.

[diagram page 42]

Figure 9. Path of the rays in the telescope of the aerological theodolite.

The measurement of rotation of the optical axis in azimuth is done by vernier 4, firmly united with the horizontal axis and moving in relation to the graduations of the stationary horizontal circle 5. With the rotation of the optical axis around the horizontal axis the vertical circle 6 rotates with it. The vertical angle is measured by means of stationary vernier 7.

Figure 9 shows the path of the rays in the telescope of the theodolite. Here L_1 represents the objective, L_2, the eyepiece. Rays coming from object AB pass through the objective and experience a full internal reflection in prism R. At A_1B_1 an image of object AB is obtained, which is viewed by eye through the eyepiece L_2. The eyepiece gives an image of object A_2B_2. In plane KK the image of the cross-hairs which serve for the accurate fixation of the position of the object is also given. The eyepiece is moved in relation to the cross-hairs in order to obtain a sharp image of the hairs in relation to the eye of the observer. In order that the image of the object can be sharply seen at the same time, the cross-hairs must lie in the image plane of object A_1B_1. Therefore the eyepiece usually consists of two main parts (Figure 10): the ocular tube 1 and the eyepiece 2 itself. By the rotation of rack 3, the eyepiece may be moved along the axis of the tube in relation to the cross-hairs 4. On the other hand, with the aid of rack 5, the eyepiece may move along the axis of the ocular knee of the telescope, which is necessary for the union of the cross-hairs with the image of the object provided by the objective.

[diagram page 43]

Figure 10. Scheme of the eyepiece of the theodolite.

One of the peculiarities of aerological theodolites is the possibility of rotation of the telescope by hand as well as with the aid of a micrometer screw. The transfer from one to the other type of movement is made freely with the aid of a friction arrangements without the uncoupling of the mircrometer screw from the gears of the guiding wheel.

[diagram page 43]

Figure 11. Diagram of coupling of the micrometer screw with the gear and friction ring.

Figure 11 shows a diagram of the coupling of the micrometer screw with the gears and friction ring. Let us inspect the rotation of the alidade of the horizontal circle. The vertical axis of the alidade 1 enters the opening of the axle box, carrying the circle, and may rotate in the box. In the upper side of the cirdle there is a ring-shaped protrusion which is embraced by the friction ring 2. It is composed of two metallic semi-rings with leather or textolitee lining and regulating screws 3. With the aid of the regulating screws it is possible to increase or decrease the friction of the ring on the protrusion of the circle. The friction ring is firmly attached to gear 4. A micrometer screw 5 is attached to the block of the alidade. The end of the screw enters the housing 6, in which it can rotate. The worm gear 7 of the screw is coupled with the teeth of circle gear 4. The regulating of the coupling is done with a bar with a spring 8.

During hand rotation of the alidade the friction of the ring against the protrusion of the circle as well as the friction of the axle of the alidade in the box are overcome. The friction ring will turn around the vertical axis of the theodolite together with the gear and the couplings with the latter by the screw and the alidade in relation to the stationary circle.

If the friction of the ring against the protrusion of the circle is greater than the friction of the axle of the alidade in the box, the friction ring and the gear will remain stationary and the screw will travel on the gear rotating together with the alidade.

A similar type friction arrangement is found in the vertical circle.

The determination of the azimuths calls forth the necessity of orienting the horizontal circle in relation to the geographic meridian. Therefore, the box of the horizontal circle enters into the stand of the theodolite and may rotate near the vertical axis. With the aid of a stop screw the horizontal circle may be secured at the necessary position.

After inspecting several peculiarities characteristic of all aerological theodolites, let us take up the description of various systems.

11. Construction of Kuznetsov, AT and ShT Theodolites.

A general view of the Kuznetsov theodolite is given in Figure 12. The base 1 is a triangular plate. At each of the legs are three setting or elevating screws 2. A bushing called the base cylinder passes through the center of the base. By means of the base screw and the threads in the base cylinder, the theodolite is set on a tripod. The horizontal circle 3 is a ring which can rotate freely around the base cylinder. The stop screw 4 holds the circle in the position desired. The alidade of the horizontal circle is a round tray 5 which can rotate around the vertical axis together with column 6. In the vertical column, the broken telescope 7 rotates together with the vertical circle 8. The power of the telescope is 12 times with a field of vision of 4 degrees. A cylindrical level 9 and compass 10 are situated on the alidade.

[drawing, page 44]

Figure 12. A general view of the Kuznetsov theodolite.

The telescope has free rotation around the horizontal axis, and, together with the column rotates around the vertical axis. The friction arrangement permits the execution of these two movements either by hand or with the aid of micrometer screws 11.

[diagram, page 45]

Figure 13. Cartridge with bulb for lighting the cross-hairs of Kuznetsov's theodolite.

1 - upon attachment the openings coincide.

[diagram, page 45]

Figure 14. Diagram of inclusion of lighting in the Kuznetsov theodolite.

The vertical and horizontal circles are graduated into degrees from 0 to 360 degrees. For the measurement of angles according to one or another circle, two verniers are installed on one plate below the eyepiece, permitting the measurement of angles up to one tenth of a degree. For the measurement of angles by a second observer there are two other verniers situated on the opposite side of the theodolite. The objective and eyepiece sections of the telescope come together in its knee-joint 12, where the triangular glass prism is located. The eyepiece tube has a rack 13 for the movement of the eyepiece in relation to the cross-hairs. The movement of the eyepiece tube for focusing on the object is done by its rotation directly by hand. Inside the eyepiece tube the cross-hairs are located.

The compass represents a box with a magnetic needle whose north end of which is observed through a window covered with a glass plate.

For night observations a special cartridge with an electric bulb (Figure 13) is used. The cartridge is attached to the eyepiece tube by two pins and has a crack-like cut to which a similar cut in the eyepiece tube corresponds. Light rays penetrating inside the ocular tube provide side lighting to the cross-hairs.

[drawing, page 46]

Figure 15. A general view of the AT theodolite.

1 - setting screw; 2 - regulating head of the setting screw; 3 - horizontal circle; 4 - stop screw; 5 - alidade; 6 - alidade micrometer screw; 7 - alidade casing; 8 - plate with index; 9 - round level; 10 - sight; 11 - rear sight; 12 - vertical circle; 13 - small rack ring; 14 - large rack ring; 15 - disc with index; 16 - lighting cartridge; 17 - micrometer screw of the horizontal circle.

When lighting is not used the cut in the ocular tube is closed with a ring on which pins are attached.

Figure 14 shows the head of the Kuznetsov theodolite tripod and the diagram of the lighting. A pocket flashlight battery serves as a power supply.

Figure 15 shows the general view of the AT theodolite. In the design of this theodolite the following differences from the Kuznetsov theodolite are present.

The setting screws have regulating heads permitting variation in the ease of turning of the screws. The horizontal circle represents a disc with sloping edges, along which degrees graduations are placed. Besides a stop screw the horizontal circle is furnished with a micrometer screw, permitting slower rotation of the circle within limited ranges.

[drawing, page 47]

Figure 16. A general view of the ShT theodolite.

1 - objective; 2 - reflecting prism box; 3 - eyepiece; 4 - vertical circle; 5 - plate with index; 6 - sight; 7 - micrometer screw; 8 - plate with index; 9 - alidade micrometer screw; 10 - stand; 11 - compass.

A casing guarding the scale of the circle and the friction device from dirt is attached to the edges of the alidade. On the casing are two windows covered with transparent celluloid strips. Opposite the windows there are indexes for the measurement of horizontal angles.

On the casing near the windows, cartridges with electric bulbs for lighting the indexes and the scales of the circles are attached. For the lighting of the field of vision of the telescope a cartridge, screwed into an opening located on the prism box is used.

For the regulation of friction devices in the horizontal circle and the casing of the vertical circle there are windows through which the degree of friction of the friction ring against the circle protrusions may be changed. A round level is placed on the alidade surface. In the window of the compass the southern end of the magnetic needle may be seen.

Measurements on both circles are made by means of indexes down to one tenth of a degree.

The ShT theodolite (Figure 16) in many respects is similar to the AT theodolite. The optical data of the telescope are the same as in the above described systems. But the ocular tube of the ShT theodolite is fixed in the telescope, so that the plane of the cross-hairs is coincident with the main focal plane of the objective. Such an arrangement is called a constant focus of the telescope on infinity. When observing, the pibt balloon is usually found at such a distance that its image is practically in the main focal plane. In this manner, the regulation of the optical system is summed up in setting of the eyepiece for a sharp image of the cross-hairs. The screen of the telescope is drawn in the central portion of the field of vision on a glass plate in the form of a cross with a break in the center.

On the box in which the prism of the telescope is located there is a plate covering three screws regulating the prism. These screws serve to move the prism in case of a need to diminish the collimating error (see 14, paragraph 3).

The friction arrangements of both circles are the same: they consist of four textolite plates fixed on two semi-sleeves drawn together by screws.

The vertical circle is open and like the horizontal circle, has two indexes. The second index of the vertical circle serves for the determination of excentricity.

The compass is removable and is fastened to the objective cover. When orienting the theodolite the compass is placed on the objective portion of the telescope when it is in a vertical position. The compass has an open northern end. For the correct placing of the compass it is necessary to make the index on the oover coincide with the index on the telescope.

For observing the balloon near the sun, a light filter -- orange or denser, green -- is placed over the eyepiece.

The scheme of illumination of the field of vision of the telescope is shown in Figure 17. A sleeve in the form of a cylinder is placed on the objective portion of the telescope. On one side a cartridge with a bulb 1 is located, and on the other side a metallic rod 2 with an inclined surface. Through an opening in the sleeve, the light from the bulb falls on the inclined surface and is reflected to the cross-hairs. By turning the rod, the degree of illumination of the cross-hairs may be regulated.

Illumination of the indexes is done by meansof a pocket flash light. Accumulators or dry pocket flashlight batteries may serve as a power supply for illumination.

The above described illumination system is characterized by its simplicity and may be applied to all theodolites.

As an example of one of the theodolites used abroad and having a series of differences in comparison with domestic instruments, we shall describe the aerological theodolite of the Watts (England) firm.

[diagram, page 49]

Figure 17. Diagram of illumination of the field of vision of the ShT theodolite.

This theodolite has a double telescope (Figure 18). The main telescope gives a 24-fold magnification with a field of vision of 2 degrees. The auxiliary telescope (finder) has a 6-fold magnification and a field of vision of 8 degrees. The eyepiece is the same for both because the focal planes of both objectives coincide. The finder serves for observations during the first moments when the angular movements of the pilot balloon are great. Transfer from the finder to the main telescope is made by means of a shift connected to a mirror serving to reflect the rays emanating from the objective of the searcher. By turning the shift, the mirror is moved to a position where it stops the rays coming from the objective of the main telescope. Depending on this the pilot balloon is observed either through the main telescope or through the finder.

[drawing, page 49]

Figure 18. A general view of the Watts theodolite.
1- main telescope; 2 - auxiliary telescope; 3 - telescope shift; 4 - cross-hair illumination regulator; 5 - vertical circle micrometer screw; 6 - alidade micrometer screw; 7 - micrometer screws lever.

In the knee joint of the main telescope a pentahedral prism is located. It has the characteristic that its rotation around the vertical axis does not change the amount of collimation.

Both circles, horizontal and vertical, are located horizontally one over the other. The horizontal position of the vertical circle is obtained because a conical gear is placed on the axle of the telescope, bringing into rotation a similar gear on the axle of the vertical circle. Measurements on both circles with an accuracy up to 1 degree are made with the aid of a common index. Measurements of tehths and hundredths of a degree are made on drums with graduations placed on the axles of micrometer screws. Micrometer screws are loosened from their gears by special levers.

In the plane of the cross-hairs there is a screen with graduated values of 3', when using the main telescope, and 15' when using the searcher. This screen serves for the evaluation of the angle subtended by the diameter of the balloon, when it is necessary to determine its altitude according to the method utilizing the angular diameter of the balloon and the vertical angle (see 39).

The system of illuminating the cross-hairs is analogous to that used in the ShT theodolite. A cartridge with a bulb is used for the illumination of the circles. Power supply batteries are located in the upper portion of the theodolite and are covered with a casing. There is no compass provided for the theodolite. Due to the great weight of the theodolite, it is more useful for stationary observations rather than field or expeditionary.

12. Ship Aerological Theodolite

Pilot balloon observations on ships are faced with a series of difficulties as a result of the motion of the ship and the variation in its course. In addition to presenting the difficulty of holding the pilot balloon in the field of vision of the telescope of a moving theocolite, the usual aerological theodolites are not useful for the determination of the vertical angle, inasmuch as during ship motion the vertical axis of the theodolite deviates from the plumb-line position. Changes in the course of the ship result in a deviation in the horizontal circle and throw off its orientation which makes it impossible to determine the azimuth in relation to north. For the elimination of these difficulties, special ship theodolites are used, whose method of orientation is different from the usual.

Figure 19 shows a ship aerological theodolite of domestic design. The theodolite has two objective tubes 1 and 2 and an eyepiece. Tube 2 during observations is directed towards the horizon, tube 1, to the pilot balloon.

Figure 20 shows a diagram of the optical system of the telescope of the ship theodolite. The ray from the pilot balloon goes through the objective O_1 of telescope A and, reflecting from prism P_1, moves in the direction of the horizontal axis of the telescope. In the path of the ray in a cut of the same tube BC a double prism P_2 with a lightly silvered surface is located which lets the ray pass to the eyepiece G. At the same time prism P_2 reflects the rays coming from objective O_2 of the second tube B. The axis of this tube is situated perpendicular to the vertical axis of the theodolite and the tube itself is fixed stationary. The rays from the horizon, coming through this tube, enter the eyepiece even with small deviations of the theodolite from the vertical.

Tube 1 (Figure 19) rotates around the horizontal axis up to 90 degrees. In the lower portion of the theodolite there is a pin which is inserted into sleeve 3 of the upper part of the rod attached in a universal joint suspension. Rod 4 has a pendulum weight 5 below. In order to diminish the swinging of the rod, rubber braces 6 are attached to the tripod, connecting the tripod with the weight shaft. With such a suspension, the theodolite participates in the ship motion only to a limited degree, however, this arrangement does not fully eliminate motion.

[photograph page 51]

Figure 19. A general view of a ship aerological theodolite.

When observing through the eyepiece the observer sees the line of the horizon and a small circle supplanting the cross-hairs. The zero index of the vertical circle seen in the telescope is pointed to some object (pilot balloon) and if at the same time the line of the horizon intersects it, then the index on the vertical circle shows the angle between the horizon and the object observed. The horizontal angle is usually determined in relation to the longitudinal axis of the ship.

Measurements according to the circles are made with verniers with an accuracy up to one tenth of a degree.

For observations on shore the theodolite is equipped with a compass and a level.

[diagram page 52]

Figure 20. Scheme of the optical system of the ship theodolite.

13. Principles of Design of Self-Recording Theodolites.

Pilot balloon observations by theodolites are usually performed by two men. For observations by only one person, especially in the measurement of angles at short intervals of time, for observations in twilight conditions, as well as with the aim of obtaining an objective record of the movement of the pilot balloon, self-recording instruments are used. In each theodolite of this type there is a device automatically registering angles at the moment of reading. The registration may be done in various ways (1) the position of the verniers or indexes in relation to the graduation on the circles is marked on a paper tape, (2) the position of the verniers is photographed on a film, (3) registration of the changes in angles is made on a drum in relative units and then processed. Finally, there is a type of registration in which the angles are not recorded, but the position of the horizontal projection of the pilot balloon is plotted on a special blank. At the conclusion of the observations, the velocity and direction of the wind may be immediately determined.

In the registration of the first type both bircles are situated one over the other horizontally. The graduation on each of them consists of raised figures in the form of cipherssimilar to typographic slugs. On one side of the instrument rollers with paper and copying tapes are installed. By pressing the tape to the circles and the indexes a print of the portion of the scale of the circles and indexes is obtained. In the reduction of observations the angle measured are determined on the basis of the prints obtained.

The principle of photographing the readings does not require special explanation.

Movements of the alidade and the vertical circle are registered in a theodolite with a relative registration of angles. These movements call forth the totation of two drums on which smoked paper is attached. Stationary pens draw horizontal segments of straight lines, proportional to the angles of turn of the telescope around the vertical and horizontal axes. Knowing the measurements of angles for the initial and final positions of the pens, it is possible to process the registrations obtained for all markings characterizing the moments of readings during the time of observation.

The scheme shown in Figure 21 is used as a basis for the theodolite with a registration of the position of the projection of the pilot balloon on a horizontal plane.

Let AA be the plane of the horizontal circle with a diagram-blank whose center lies at point O. Let us suppose that the pilot balloon is released at point O and after 1 minute is found at point P. Its altitude H, evidently is equal to the vertical velocity. Let us assume that the circle after the same interval of time traversed downward on a distance h and took the position A_1A_1. It is not difficult to see that the extension of the sight line OP to the meeting with the plane of the circle at point C_1 determines the projection of the balloon 1 minute after its release. Actually, from the similarity of triangles POC and OC_1O_1, it follows that

$$O_1C_1 = \frac{h}{H} \quad OC$$

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In other words, the segment O_1C_1 gives the distance to the projection of the pilot balloon on a scale of $\frac{h}{H}$.

The movement of the circle along the vertical on a distance of 2h, 3h and so forth, makes it possible to obtain in the same manner the position of the projection through 2, 3 and so forth minutes. Inasmuch as the diagram-blank is oriented in relation to the cardinal points, the result of the successive recording of the projection is the projection of the path of the pilot balloon.

The accuracy of the data of felocity and wind direction obtained as a result of processing such a recording is not great, because the scale of the recording is very small, and with great wind-velocities the projection often falls outside the blank.

An increase in accuracy in the determination of the wind in relation to the measurement of angular coordinates of the pilot balloon requires the improvement of aerological theodolites. For this it is first of all necessary to improve the optical characteristics of the telescope, increase the accuracy of readings, ease the aiming on the balloon, and also decrease the possibility of appearance of instrumental errors and ease the operation connected with their elimination.

14. Sources of Instrumental Errors in Aerological Theodolites and Determination of Corrections.

The main sources of errors in the determination of angular coordinates by aerological theodolites are the various deviations from the basic requirements which the instrument itself must satisfy. Incorrectness in the coupling of the theodolite axes with each other and with the circles, in the setting of the level on the alidade and several others lead to the appearance of instrument errors. The establishment of their character and size, i.e., the check of the instrument, makes it possible to introduce the corresponding correction in the measurements of angles, with which the quality of observations is improved.

The following are examples of the more important errors which must be considered during observations:

(1) errors related to the incorrect setting of the level on the alidade;

(2) errors related to the incorrect setting of the index (vernier) of the veritcal circle;

(3) collimation errors;

(4) exentricity of the horizontal and vertical circles.

Let us study them in the above stated order.

1. The level serves for the setting of the vertical axis of the theodolite according to a plumb-line, i.e., for its leveling. The level must therefore be reliable and capable of being checked and regulated prior to each observation.

In aerological theodolites, round and -- more accurate -- tubular levels are encountered.

The check of a tubular level is done in the following manner. The theodolite is leveled by the level using, as is usual, the footscrews. Then the alidade is turned so that the axis of the level again is along the direction of the two screws, but in an opposite direction of the ends of the level (180 degrees). The displacement of the bubble from the zero point will show that the axis of the level is not perpendicular to the vertical axis of the theodolite. Elimination of this condition or the regulation of the level is done so that half of the amount of deviation is eliminated by the correction screws or the level, and the second half -- by the foot-screws. If it is found that at the turning of the alidade the bubble again moves from the zero point the regulation is repeated.

For the check of the round level by means of foot-screws, the bubble is brought to the zero point and the alidade is turned. The displacement of the bubble shows the incorrectness of its setting on the alidade. For the regulation of the level the direction of the greatest displacement is determined and, removing the screws fastening the level to the alidade, a foil leaf is placed under the body of the level in such a manner that after replacing the screws of the level, the bubble will return to a point half-way between the zero point and the point of its farthest deviation. Then the bubble is brought to the zero point with the aid of the foot-screws. In case of further displacement of the bubble with a turning of the alidade, the regulation is repeated.

2. The incorrect setting of the index (vernier) of the vertical circle results in the determination of the vertical angle being made with the one and the same error for all positions of the pilot balloon. This systematic error must be evaluated before observation. It can be determined from the following considerations.

[diagram page 54]

Figure 22. Diagram for the determination of the error in the vertical circle.

On Figure 22, let the circle with center O represent the vertical circle of the theodolite with a clockwise increase in degrees, and HH, the horizon. In directing the theodolite to a distant point A, the line OA represents the optical axis. If index J or the vernier are correctly established, then according to the position of the telescope called "normal sighting" the reading by the index or the zero division of the vernier would give the correct vertical angle δ. In case of an incorrect setting of the index the reading in this position would give

[formula page 54] (33)

where $\Delta\delta$ is the error in the determination of the vertical angle. After rotating the telescope through the zenith and directing it to the same object the optical axis will take up the position OA' symmetrical to the first in relation to the horizon. In this position which is called "inverted sighting" a division greater than δ $+ \Delta\delta$ will fall under the index with the telescope with circle turning through an angle equal to $180 - 2\delta$. Consequently, in the inverted position, the reading on the vertical circle qill be equal to

[formula page 55] (34)

Adding (33) and (34), we obtain

[formula page 55],

from which

[formula page 55] (35)

The error in the determination of the vertical angle will have a sign in relation to whether the sum M + N is less or greater than 180. Evidently, the correction must be introduced with the opposite sign, namely, if

[formula page 55]

then the correction will be minus, if

[formula page 55],

then the correction must be taken with a plus sign.

In this manner the constant error in the reading of the vertical circle may be determined with the aid of sighting on a distant object at two positions of thetelescope: "normal sighting" and"inverted sighting". The magnitude and sign of the correction will give the following formula:

[formula page 55]. (35')

When the error of the vertidal circle is great, or when it is desirable, in general, to eliminate it, then it follows that the plate containing the index should be moved in such a way that the error be reduced to zero.

3. The collimating error appears in the case where the optical axis of the telescope is not perpendicular to the horizontal axis.

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The reason for such a condition may be the incorrect setting of the prism of full internal reflection or a displacement of the cross-hairs in relation to the horizontal axis. The angle of deviation of the optical axis from the perpendicular to the horizontal axis is called the collimation angle, or collimation [error].

Figure 23 shows how an incorrect setting of the prism produces collimation [error]. In a correct setting of the prism (shown by dotted lines) we shall see in position a, at the intersection of lines at point O, the image of object T, lying on the extension of the optical axis TB perpendicular to the horizontal axis OB. In an incorrect position of the prism (shown by solid lines), we see the image of object T' lying on the extension of optical axis T'B' not perpendicular to the horizontal axis. The angle between TB and T'B is the collimation angle k.

[diagram page 56]

Figure 23. The effect of the incorrect installation of the prism upon collimation is the normal sighting (a) and inverted sighting (b) positions.

If we turn the telescope of the theodolite through the zenith and turn the alidade 180 degrees, (position b) then in the intersection of lines we shall see object T". In order to bring the image of T' into point O, it is necessary to turn the telescope, in this case, to the right through an angle 2k. Consequently, with the existence of collimation [error], besides a difference of 180 degrees, readings of the horizontal circle before and after inverted sighting, will differ from one another by double the collimation angle.

Actually, in Figure 24, let HH be the horizontal axis, AB the perpendicular to the horizontal axis in the plane of the horizon, OA_1 the optical axis which together with AB makes the collimation angle k. Having directed the optical axis to object T' in the normal sighting position, we measure α_1. Keeping the position of the alidade let us move the telescope through the zenith. The optical axis will then take the position OB_1, symmetrical with respect to axis HH. In order that we again see in the cross-hairs the object T', having the telescope in the inverted sighting position, we must turn the alidade in the direction of increasing angular readings by $180^\circ + 2k$, and therefore with inversion the new reading will equal $\alpha_1 + 180^\circ + 2k$, i.e.,

[formula page 56]

from which

[formula page 56] (36)

In this manner, the collimation angle is determined by formula (36), where $?_1$ is the reading of the horizontal circle in the normal sighting position and $?_2$, the reading of the horizontal circle on the same object in the inverted sighting position.

The collimation angle has a plus sign if $(?_2 - ?_1)$ is greater than 180 degrees, and a minus sign if this difference is less than 180 degrees.

The collimation [error] sign is determined by the direction of displacement of the prism and consequently by the direction of deviation of the optical axis. For the case shown in Figure 24 the magnitude of the collimation [error] is taken with a plus sign because the deviation is directed to the side of increased angles.

The correction of the readings of the horizontal circle due to collimation [error] is not constant, and depends not only on the size of the vertical angle under which the optical axis is found.

Let us look at Figure 25, in which HH is the horizontal axis, OA the perpendicular to axis HH lying in the plane of the horizon, OZ the direction to the zenith, OA_1 the optical axis making the collimation angle k together with line AO.

Figure 25. The effect of the vertical angle upon the size of the collimation correction.

In the position of the optical axis OA directed toward an object on the horizon, for simplicity of argument let the 0 degrees of the horizontal circle be placed under the zero graduation of the vernier and them made fast. With the rotation of axis OA_1 its end will describe not an arc of a great circle, but an arc A_1Z_1 parallel to it and not passing through the zenith. With the increase of the vertical angle the optical axis will therefore deviate more and more in azimuth. If the optical axis be directed to point M situated at the vertical angle ? , then the reading of the horizontal circle in this position must differ from 0 degrees by the value A_1A_2, which is the correction due to collimation. It is not difficult to see that with the increase of the vertical angle this correction increases.

Using the relationship of spherical trigonometry we may establish that

[formula page 57 (37)]

and consequently,

[formula page 57]

In the table five absolute values of corrections for collimation for different values of the collimation angle and readings of the vertical angle are given.

4. The eccentricity of the horizontal circle and alidade is brought about by the fact that the centers of the circle of the alidade do not coincide. In the case of eccentricity of the vertical circle the horizontal axis does not run into the center of the vertical circle.

Table 5

Values of collimation corrections in relation to the magnitude of the collimation angle and readings of the vertical circle.

Vertical angle	Collimation angle k

Inasmuch as aerological theodolites are usually equipped with two diametrically opposed verniers or indexes of the horizontal circle, the presence of eccentricity may be determined and the magnitude of the correction fixed from the following arguments (Figure 26).

Let point O represent the center of the horizontal circle, point O_1

[diagram page 58]

Figure 26. Eccentricity of the horizontal circle and alidade, the center of the alidade (projection of the vertical axis), N_1N_2 the lines of verniers, D_1D_2 the diameter of the circle. Evidently the reading α_1 according to the main vernier N_1 will be diminished by angle $\Delta\alpha$, expressed by arc N_1D_1. At the same time the reading α_2 according to the second vernier N_2 will be greater than the main vernier by the magnitude 180 degress plus $2\Delta\alpha$, i.e.

[formula page 58]

from which we have the correction

[formula page 58] (39)

Consequently the correct reading of α may be computed with the aid of the expression

[formula page 58] (40)

The determination of the correction for the eccentricity of the vertical circle is made analogically to the above described.

In order to make readings according to one vernier it is necessary to check the theodolite for eccentricity and, in case of determining the phenomenon, to compile a table or graph of corrections.

In addition to the errors described we should also invite attention to the error whose cause is the non-perpendicularity of the horizontal axis of the theodolite to the vertical axis. If we designate the angle of deviation of the horizontal axis from the plane perpendicular to the vertical axis by i, then the correction to the readings of the horizontal circle $\Delta\alpha_i$ γ will be expressed by the following relation:

[Formula page 59], (41)

where δ is the vertical angle.

The value i is determined by sighting a sufficiently highly situated distant point (usually a star) in the normal sighting and the inverted sighting positions.

When working with theodolites other faults may be encountered which may be eliminated on the spot. For example the tight rotation of the alidade when turning it by hand or the tight rotation of the telescope may be eliminated by regulation of the friction rings. The difficult or "dead turning" of the micrometer screws may be eliminated either by the regulating screws or the variation in the firmness of the friction rings. Faults in the compass may also be easily eliminated on the spot.

15. Selection of the Site for Making Pilot Balloon Observations and Setting Up of the Theodolite.

The site for the setting up of the theodolite must be sufficiently open -- the surrounding objects must not rise above the horizon by more than five to eight degrees in all directions. Under field conditions the theodolite is set up on a support (tripod). Under stationary conditions it is more convenient to use a post sunk into the ground, on whose upper platform the theodolite is placed.

Having fastened the theodolite on the tripod or on the post it is prepared for observations. The preparation of the theodolite consists of the following preparations: (1) leveling, (2) regulation of the eyepiece, and (3) orientation.

1. The leveling of the theodolite, i.e. its establishment according to level, is made by the foot-screws. By turning the foot-screws the bubble of the level is brought to the zero point.

2. For the regulation of the eyepiece it is necessary: (a) to direct the telescope to the sky and by the rotation of the rack closest to the eye to bring the eyepiece to a sharp representation of the cross-hairs; (b) to direct the telescope to a distant object at a distance of not less than 200 to 250 meters and by the movement of the whole ocular tube to find such a position that will give a sharp representation of this object. Under such a position the image plane of the cross-hairs must coincide with the image plane of the object. An insufficiently accurate position will give the image of the object a parallactic displacement in relation to the cross-hairs.

3. In observations from one point the orientation of the theodolite is summed up in that the horizontal circle must be established in such a position that readings by it will be equal to the azimuths of the optical axis. In other words, in pointing the optical axis to the north the reading on the horizontal circle must

be equal to zero degrees, and consequently, by pointing it east, to 90 degrees, south, to 180 degrees, and west, to 270 degrees.

The orientation of the theodolite may be effected either by a compass or (under stationary conditions) by artificial objects. Artificial objects are stationary, sufficiently distant (lightning arrestors on smoke stacks, spires on tall towers and belfries ~~bellfrys~~, radio transmitting towers), whose azimuths have been established earlier.

The orientation of the theodolite by the compass is done in the following manner. Having freed the magnetic needle, the alidade is turned so that the direction of the needle coincides with the axis of the compass. It is evident that in this position the direction of the optical axis will coincide with the direction of the compass axis.

It should be remembered that the visible end of the needle may be either the north or the south end, and the direction of the objective of the telescope may coincide with the visible end of the needle or may be turned 180 degrees in relation to it. Knowing which end of the magnetic needle is visible, it is always possible to determine whether the objective of the telescope is directed either north or south. In connection with this, the division of the horizontal circle corresponding to the direction of the objective of the telescope is set under the zero graduation of the vernier or under the index to be used for reading, taking into account the magnetic deviation at the observation site.

The magnetic deviation must be taken into account because the theodolite must be oriented according to the geographic and not the magnetic meridian. In case the magnetic deviation is east, the division zero degrees plus Δb or 180 degress plus Δb where Δb is the magnitude of the deviation expressed in degress is brought opposite the index. If the deviation is west then the division zero degrees minus Δb or 180 degrees minus Δb is placed under the index.

The order of the operations of making the corresponding divisions of the circle coincide with the indexes of the alidade are determined by the system of the theodolite, but the principle remains the same.

When orienting the theodolite by artificial objects, the telescope of the theodolite is pointed at the object in such a manner that its image coincides with the cross-hairs, and the index selected for reading shows the division on the horizontal circle equal to the azimuth of the artificial object. As a result of orientation the readings on the horizontal circle will correspond to the azimuth of observed pilot balloon under conditions that take into consideration instrument errors.

In pilot balloon observations from one point it is customary to take into account the error of displacement of the index of the vertical circle if it is equal to 0.3 degrees or more. In base line observations the correction is introduced in cases where its magnitude exceeds 0.1 degree. The determination of collimation [error] in observations from one point serves for the establishment of the usefulness of the theodolite for the observations. The theodolite is considered useful if the collimation [error] does not exceed 0.5 degrees. In base line observations the collimation correction in readings is introduced in the case when its size exceeds o.1 degrees.

16. Hydrogen for the Filling of Rubber Casings of Pilot Balloons and Radiosondes.

Pilot balloon casings and casings used in ascents of sounding balloons and radiosondes are usually filled with hydrogen and comparatively rarely with helium.

In a chemically pure state hydrogen is a gas without odor or color. At a temperature of 0 degrees and pressure of 760 millimeters, 1 cubicmeter of hydrogen weighs 0.69 kilograms. Hydrogen is 14.4 times lighter than air, as a consequence of which it finds use as a lifting gas. The specific lifting force of chemically pure hydrogen underthe stated conditions is 1,293 - 0.090 = 1,203 kilograms. Commercial hydrogen used for the filling of casings contains admixtures which make it heavier and decrease the lifting force. Therefore, the specific lifting force of hydrogen as contained in balloons or as obtained with the aid of gas generators is on the average 1.1 - 1.2 kilograms.

As follows from the determination the lifting force of hydrogen varies depending on temperature and pressure of the air and gas. Assuming the values of temperature and air pressure and hydrogen to be equal, it is possible to compute the pressure and temperature by the formula

[formula page 61] (42)

where e is the specific lifting force (in kilograms), p is the pressure (in millimeters), T, the absolute temperature (in degrees), and under normal conditions, the density of hydrogen is taken as equal to 0.130 kilograms per cubic meter.

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In a mixture of air or oxygen, hydrogen burns. In a mixture of oxygen from the air hydrogen forms a detonating gas which explodes from fire or sparks if the mixture of air to hydrogen is 25 to 96 percent.

The presence of dust in hydrogen makes it a carrier of static electricity charges, and the electrification of the gas conductor at the gas nozzle may bring about a suitable condition for the discharge of electricity, and this may bring about a burning of the hydrogen or even an explosion.

In avoiding the creation of a fulminating mixture in places where hydrogen is obtained or stored, also where balloons are filled, a ventilating system must be provided. To avoid fires and explosions, fires and sparks (firing of stoves, lighted cigarettes, electric apparatus and electric lamps with spark plugs) must not be allowed in the presence of hydrogen.

Helium is heavier than hydrogen by about 2 times; it does not burn and therefore is safe. The specific lifting force of helium is only 8 percent less than the specific lifting force of hydrogen and for casings of small dimensions their difference has little effect. The wide use of helium for the filling of casings is as yet prevented by the difficulty of obtaining it and by high prices.

Hydrogen for the filling of balloons comes to aerological stations in steel tanks or is obtained on the spot with the aid of gas generators.

When filling aerostats, special gas holders are used.

17. Construction of Hydrogen Tanks

The hydrogen tank represents a hermetically sealed vessel of cylindrical form with a rounded bottom and elongated neck (Figure 27). The length of the tanks is 1.53 meters, the outside diameter, 22 centimeters, and the thickness of the walls, 8 millimeters. The weight of the tanks is about 62 kilograms. The volume of the tanks is equal to 40 liters. The hydrogen in the tanks is in a compressed state under a pressure of 150 atmospheres. Under a normal pressure the hydrogen compressed in the tank will have a volume of 5.5 cubic meters. A gauge is used to determine the amount of hydrogen in the tank. The gauge is located at the outlet. A high pressure valve is attached to the elongated neck of the tank. This insures the even release of gas. The valve is guarded from damage by a cast iron helmet covering the neck.

Figure 28 shows the construction of the valve. By its lower part which has a conical thread, the valve is screwed into the neck of the tank 1. Along the axis of the valve runs a channel with a side outlet ending in a sleeve 2 for the release of gas from the tank. The outlet is closed by a plug 3 with a left-handed thread. The channel along the axis of the valve is shut by a screw cork or a slide valve 4 with a quadrihedral tail entering into sleeve 5, into which a similar tail of the spindle 6 enters. On the upper end of the spindle a pilot wheel (rosette) 7 is placed by the turns of which it is possible either to raise or lower the cork in its seat. In the lower part of the cork is a gasket of red copper, which, pressing against the mouth of the channel closes the escape of gas from the tank.

In order to prevent the escape of gas upward through the valve a special device in the form of a fiber gasket 8 and a compression nut 9 is provided to guard against the breach through the valve. By turning the pilot wheel to the left the release of gas to the sleeve is effected. A hose for the filling of casings is attached to the sleeve. The left-handed thread of the sleeve serves to differentiate hydrogen tanks from tanks of other gases.

In order to prevent accidents involving people and in the interest of insuring the operation of the tanks it is necessary to comply with the regulations in the handling of tanks and in the release of gas from them.

(1) In order to prevent electrical discharges the tank is grounded when releasing gas.

(2) The release of hydrogen from the tank is prohibited in the presence of fire.

(3) After the release of hydrogen the valve must be immediately shut firmly in order to prevent the leakage of hydrogen into the air.

(4) It is prohibited to throw or strike tanks when moving them.

(5) When lifting or turning the tank it should not be grasped by the valve nor should the tank be leaned against the valve.

(6) When transporting tanks they should be provided with rope wings or other padding and shielded from the action of sunlight.

Hydrogen tanks may be stored in special locations -- a hydrogen warehouse or in the open air under roof and guarded. A mud hut or a fireproof building provided with ventilation may serve as a hydrogen warehouse. The construction of a hydrogen warehouse is made at a distance of not less than 50 meters from residential houses or warehouses.

18. Obtaining Hydrogen With the Aid of Gas Generators

In places of great distances from central regions, under field conditions, and also in the absence of hydrogen tanks, hydrogen is obtained on the spot.

Various methods of obtaining hydrogen, as for example by means of zinc and sulphuric acid from hydrogenous calcium through electrolysis, appear unprofitable either due to high expenses or due to the fact that the hydrogen obtained has dangerous admixtures.

In the practice of gas generation for the casings of pilot balloons and radiosondes as well as for the filling of aerostats the so-called alkalization method has found application. In this method aluminum and caustic soda solution or silicon and the same alkali solution is used to obtain hydrogen.

At the present time ferrosilicon ($SIFe_2$), caustic soda ($NaOH$), and water are used as chemicals to obtain hydrogen by the alkalization method. Ferrosilicon is an alloy of silicon and iron and represents a hard substance of a dark gray color.

Caustic soda is a white dense mass of fibrous crystalline structure; it has a burning effect on skin, clothes, and footwear.

Under the simultaneous action of caustic soda, ferrosilicon and water a chemical reaction occurs which can be conveniently expressed by the following equation:

[formula page 63]

Working formulas have various variants depending on the interdependence of parts of ferrosilicon and caustic soda.

As a result of the reaction, a silicate of sodium or liquid glass and hydrogen are formed. The reaction is accompanied with a considerable output of heat.

In the remaining solution a certain amount of caustic soda, silicon, and other substances having not entered the reaction are disclosed. The remainder contains a strong causticity and is therefore poured into a deep guarded pit.

At the present time in the aerological net of the USSR a tank gas generator with a capacity up to 2.5 cubic meters of hydrogen from one full charge is used.

The tank gas generator (Figure 29) consists of two main parts: reactor 1 and head 2. A standard hydrogen tank serves as the reactor. In it the chemical process takes place under a pressure reaching 100 atmospheres with a rise in temperature up to 250 degrees. The reactor is set up on a support or A-frame 6 aided by a girdle and two pivot shafts 7. Handles attached to girdle 8 situated in the lower part of the reactor permit it to be turned in the necessary position.

The head of the gas generator is screwed on the neck of the reactor through which it is charges. Gauge 4, for the control of pressure in the reactor, and valve 5 limiting the magnitude of this pressure, are attached to the side openings of the head. The usual tank valve 3 is attached in the upper part of the head, and a durite tube is attached to the side sleeve.

A continuous thin silver plate firmly pressed to the opening leading to the reactor with the aid of a screw cork containing a hole

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is the main part of the safety valve. If the pressure in the reactor rises to 110 atmospheres, i.e. over the allowable working pressure of 100 atmospheres, then the safety silver plate will burst and the pressure diminish.

Depending on whether hydrogen is needed for the filling of pilot balloon casings or casings for radiosondes a certain quantity of chemicals is placed in the reactor to generate gas. For example, when generating hydrogen to fill casing No 100 (for the release of radiosondes) 2.4 kilograms of ferrosilicon, 2.6 kilograms of caustic soda, and 10 liters of water are required.

diagram page 64

Figure 29. A general view of the tank gas generator. 1 -- reactor; 2 -- head of the generator; 3 -- tank valve; 4 -- gauge; 5 -- safety valve; 6 -- support; 7 -- girdle with pivot shafts; 8 -- girdle with handles.

The charge of chemicals is done in the following order: first powdered caustic soda is poured through the neck, then water and later silicol. During the whole time of the reaction it is necessary to watch the rising pressure on the gauge, and when the indicator of the gauge approaches the graduation corresponding to 70 atmospheres the valve should be opened to let the gas enter the casing, and the valve is closed when the pressure reaches 45 to 50 atmospheres. If it is necessary to continue the filling of the casing then this is done after the end of the reaction. It should be noted that after the filling of the casing with hot gas its

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cooling should be awaited and only then to make the measurement of elements determining the vertical velocity of the pilot balloon.

After using the generated hydrogen the reactor should be washed clean of the products of the reaction.

In the work of generating gas it is very important to comply with safety rules in order to prevent the possibility of burns from caustic soda and also to prevent dangerous pressures from forming in the reactor and to prevent the formation of fulminating gas and an explosion. Therefore, the powdering of caustic soda and charging the reactor with it must be done in special clothing and goggles. In order to prevent burns from the stream of gas escaping through the valve it is prohibited to stand in front of the safety valve. The remains of the products of thereaction are poured into a guarded pit.

In order to prevent the appearance of electrical charges the support and the reactor, placed on a wooden floor or asphalt, must be grounded.

Where gas is generated at the working site ventilation must be provided.

When generating gas and filling the balloons it is necessary to take all necessary steps towards the elimination of gas, fire, or sparks.

19. Casings Used for Pilot Balloons, Radio Pilots, and Radiosondes

One of the main requirements for casings used for pilot balloon and radio pilot observations, and also for the ascent of radiosondes, is its elasticity, permitting the casing to freely expand with diminishing air density. As we have seen, this condition determines a sufficiently constant vertical velocity almost for the entire time of ascent if there is no diffusion of gas. Therefore, besides elasticity, casings must have small gas transmissability.

Up to 1942 pilot balloon casings were prepared by cementing together separate segments of natural rubber. The thickness of the casings was from 0.4 to 0.5 millimeters. In 1942 a method of preparing casings of natural rubber latex (liquid rubber) was developed in the USSR. Since 1946 casings are being made of Soviet synthetic rubber. Tests of casings prepared of synthetic latex have shown that according to physical and mechanical properties synthetic rubber has advantages over natural rubber. Its gas transmissability is lower than that of natural rubber. It is less inflammable and more stable in the presence of organic and mineral solvents.

Seamless casings are prepared by dipping a wooden or metallic spherical mold into a bath containing latex. When the mold is dipped a thin layer of rubber is formed which under repeated dipping becomes thicker, up to the required thickness. With this method of production it is not always possible to attain an equal thickness of casing and this results in a misshapen form at its filling. During ascent an uneven thickness of the casing may result in a premature burst at the thinnest point.

An improved method for the preparation of casings consists of the spraying of latex by a centrifugal method inside a spherical mold. Then the casings are produced sufficiently evenly in thickness.

In order to give the rubber of the casings a greater degree of stretch and elasticity even at low temperatures the material of the casings undergoes vulcanization, i.e. it is soaked through with sulphur.

For a better visibility of pilot balloons during observations under cloudy conditions, the casings are painted red, black, or brown.

The casings are provided with a neck through which they are filled with gas.

Depending on their function prepared casings have different sizes and weight. The nomenclature of the casings is by the size of the diameter (in centimeters) at the moment when the casing has taken the form of a sphere but has as yet not stretched. At the present time casing Nos 10, 20, 30, 50, 100, and 150 are produced. Their characteristics are given in Table 6.

TABLE 6

Characteristics of Casings

Number of Casings	Weight (In Grams)	Length of the Circumference in Normal Fillings (in Centimeters)	Length of the Circumference at Bursting (in Centimeters)	Average Altitude at Burst (in Kilometers)	Color of the Casings
					Black, light brown red.
					Black, light brown, red
					Light brown
					Light brown
					Light brown
					Light brown

Casings Nos 10, 20, and 30 are used for pilot balloon observations. Casings Nos 10 and 20 are also used in observations without theodolites when determining the height of clouds. Casing No 50 serves for radio pilot balloon observations and in exceptional cases for the ascent of radiosondes. Casing No 100 is the main type of casing used for radiosonde ascents, and No 150 is used to raise the ceiling of radio soundings. The specifications for filling shown in the table correspond to the functions of each type of casing.

During the rise of the pilot balloon or of the radiosonde the casing expands and the volume of the ballon increases inversely proportional to the change in the density of the air. This expansion continues until such time as the thickness of the casing reaches its limiting size, when the casing bursts. It is evident that a certain circumference of the great circle of the balloon which is called the bursting length of the circumference corresponds to the moment of burst. The average size of the bursting circumference may be determined empirically. Knowing this size, it is not difficult to compute the average bursting altitude. If by V_o and V_n we designate the volume of the balloon at the initial moment and at the burst of the casing, and by ρ_o and ρ_n the density of the air at those same instants, then we can state that

[formula page 66]

Substituting the relation of volumes by the relation of circumferences cubed, we obtain

[formula page 66],

from which

[formula page 66].

Equation (43) determines the density of the air at the level of the burst of the casing, inasmuch as all the values on the right side are known.

If we assume C_o as the circumference at normal filling, C_n the average bursting circumference, ρ_o the average air density on the ground, then according to formula (43) the average air density at the bursting level can be determined. From here it is not difficult to determine the maximum altitude of the pilot balloon or radiosonde.

The quality of the casings, besides the properties of the material, and the method of preparation, depends also on the storage conditions. It is known that the rubber of the casing decomposes if kerosene, gasoline, oil, or acids come into contact with it. Direct solar radiation also causes deterioration in rubber. Consequently we must avoid the storage of casings under conditions which may bring about the action of the stated factors. Besides, in places where casings are found the air temperature should not go below zero degrees or rise above 15 degrees and the humidity must not be less than 70 percent.

It has been established that with cooling or continuous storing synthetic rubber crystallizes, and the crystallizing of the casing does not allow normal expansion. However, by heating the casings the crystallization is eliminated and their elasticity is fully restored; therefore, prior to using the casings they are heated by immersion into boiling water for five to ten minutes or by any other source of heat.

20. Selection of Casing Size and Filling Prior to Pilot Balloon Observations

The selection of casings is done in each separate case depending on the wind and the cloudiness below as well as in higher layers of the atmosphere. With a cloudy sky, when the length of the observation is limited by the entrance of the pilot balloon into the clouds, the selection of casings is based on the height of the clouds. In a strong wind the pilot balloons quickly leave the point of observation and in the case of small sized balloons observations may cease due to the fact that the balloons will no longer be seen. Finally, the selection of casings is based on the required maximum altitude for the determination of the velocity and direction of the wind.

In this connection, casing No 16 is used in low overcast. In medium overcast casing No 20, main type, is used. In a clear sky, with a strong wind, as well as in those cases when it is desirable to obtain data of the wind up to high altitudes, casing No 30 is used.

In night observations, in addition to casing No 20, casing No 30 is also used, namely, when it is necessary to determine the wind to a considerable altitude, which requires a heavier lantern suspended from the balloon and the filling of the balloon to a greater vertical velocity.

For the filling of the pilot balloon or the radiosonde casing from the tank or gas generator, a durite tube is used. One end of the tube has a throw-on bolt by means of which the tube is attached to the sleeve of the valve. The second end of the tube is attached to the neck of the balloon or is attached to the gas connection of the scales through which the hydrogen is passed to the casing.

The filling of the balloons is usually done up to a certain norm corresponding to a definite circumference varying with each type of casing. If a standard vertical velocity for the pilot balloon is required, the casing is filled in such a manner that the balloon will have a free lifting force as found according to the nomograms or tables.

After the casing has been connected to the tube through its appendix, the valve is opened by a slow turn to the left so that the hydrogen goes into the tube and the casing.

The measurement of the circumference is made with the aid of a measuring tape divided into centimeters. The tape is placed along the great circle of the balloon before the completion of filling and by one of the ends it is observed when the length of the circumference reaches the norm.

After this, the neck is tied and the determination of the free lifting force is begun. For this a number of weights are suspended from the balloon so that they will balance the pilot balloon in the air. It is evident that the weight of the balances at this moment determines the free lifting force of the pilot balloon.

Filling up to the specified free lifting force or up to the value found according to the nomograms or tables can be conveniently done with the aid of scales adapted to this work. The balloon being filled is attached to one of the plates of such scales, and on the same plate a weight equal to the required free lifting force is placed. The balloon is filled until the scales balance (Figure 30).

When filling casings it should be borne in mind that the casing filled over the norm may burst prematurely, and a pilot balloon not fully filled will be quickly driven to the horizon and will be lost in the background during a strong wind.

The filling of pilot balloons requires the compliance with all regulations for handling hydrogen about which we have spoken above. The danger of the formation of electrical charges should be especially mentioned. To avoid the appearance of static electricity charges, the hydrogen tank or generator, as well as the nozzle of the tube, must be grounded, and the casing must not experience friction against any object.

21. Technique for Making Pilot Balloon Observations

Usually observations are made by two persons, but in certain cases they may be made by one. Of the two observers one is considered the assistant.

The observer sets up the theodolite for observations, i. e. levels it, adjusts the eyepiece, and orients the theodolite by man made objects or with the aid of the magnetic needle.

The determination of instrumental errors during observations from one point is made every ten days, in base line observations -- before and after each observation.

The assistant observer fills the casing and then measures the length of the circumference of the pilot balloon and its free lifting force and records the measurement data in the observation log.

Before observations the pressure, temperature, air humidity, wind and cloudiness are recorded in the observation log.

Prior to the release of the pilot balloon the time of release (mean solar) with an accuracy to one minute, is recorded. At the moment of release a stop-watch is started and after 10 to 15 seconds the pilot balloon is brought into the field of vision of the telescope using the front and rear sights and later the micrometer screws. At the moment of reading the image of the balloon must be found at the cross hairs. During the first three minutes readings are taken each 0.5 minutes, later, each minute to the end of the observation. Five seconds prior to reading the assistant observer gives a warning signal and then gives the signal for the reading.

Usually the reading of the vertical circle is done by the observer, and the horizontal by the assistant, who takes down the readings in the observation log.

Observations must be continued as long as the pilot balloon is still visible in the theodolite. Reasons for the cessation of observations may be the following: (1) the pilot balloon entered a cloud, (2) burst, (3) was covered by a low lying cloud, (4) became invisible due to blending with the background, (6) lost from the field of vision, (7) during night observation the lantern either went out or burned out.

The moment when the pilot balloon entering a cloud begins to fog is noted with an accuracy to one second, because, by using the interval of time from the moment of the release of the balloon to the above mentioned moment the lower limit of the cloud is determined.

Upon completion of observations the data on the reason for the cessation of observations, on the direction into which the pilot balloon disappears and on the cloudiness and wind after ascent are recorded in the observation log.

22. Pilot Balloon Observations at Night

In order to make pilot balloon observations at night small paper lanterns are used whose light is observed in the theodolite. A view of such a lantern is given in Figure 31. The lantern is made of cardboard and pasted over with transparent paper. Inside the lantern there is a stand for a wax candle with a length of two to three centimeters.

[diagram page 68]

Figure 30. Scales for filling pilot balloons up to a certain free lifting force.

1 -- end of the tube; 2 -- rubber tube; 3 -- angle tube.

The candle is lit prior to the release of the pilot balloon.

Then the lantern is attached to the pilot balloon with the aid of a strong cord 1.5 to 2 meters in length. After this the release of the pilot balloon with the lantern is effected.

Instead of the stated lantern it is possible to use a lantern of another type, for example, a round one.

[diagram page 69]

Figure 31. Lantern for night pilot balloon observations.

As a stronger source of light it is possible to use an electric lamp powered by a dry element or a small battery.

The theodolite for night observations must be prepared ahead of time. In contrast to day observations, the observer brings the image of the luminous lantern to the cross hairs at the moment of reading.

In the determination of the free lifting force it is necessary to take into account the weight of the equipped lantern.

23. Processing of Pilot Balloon Observations for the Determination of Wind

As was shown in § 1, for the determination of the velocity and the direction of the wind in the free atmosphere by the pilot balloon method, it is necessary to construct a horizontal projection of the path of the pilot balloon. Such a construction is possible if at successive instants of time the altitude of the pilot balloon, the azimuth, and the vertical angle of the direction to the balloon are known. The altitude of the balloon, as was stated, is computed with the supposition that the vertical velocity is constant according to

[formula page 70],

where W is the vertical velocity and t, the time elapsed from the moment of the release of the balloon to the moment of reading. The azimuth and the vertical angle are measured by means of a theodolite during observations.

Using the stated three coordinates it is possible to construct for all moments of readings a projection of the balloon by joining the projection of the path of the pilot balloon in the form of some curve.

[diagram page 70]

Figure 32. The horizontal projection of the path of the pilot balloon and computations of the velocity and direction of the wind.

The position of the projection of the balloon for successive moments of time may be determined by the horizontal distances of the balloon from the point of observation and from azimuths. The horizontal distances may be found by formula

[formula page 70]

where δ is the vertical angle.

This same value may be obtained by a geometrical construction of a right angle triangle formed by the point of observation, the pilot balloon and its projection.

Let us suppose that the broken line $OC_1C_2C_3C_4$ (Figure 32) represents the projection of the path of the pilot balloon. Then the segments between projections OC_1, C_1C_2, C_2C_3 and C_3C_4 will characterize the velocity of the wind according to magnitude and direction. These segments determine the mean velocity of the wind in layers passed trhough by the balloon in the interval of time between successive readings. The velocities of wind obtained refer to the center of the layer determined as the arithmetical average of the altitudes at the beginning and end of the given interval of time.

Velocities and wind directions may be determined also be computations of formulas not using graphical constructions. Such a type of analytical method was developed by V. M. Mikhel, for example.

Computations according to this method consist of the following. For the determination of the wind characterized, for example, by segment C_2C_3, let us separate wind vector 1 into two components: radial -- 1_r according to the direction of the horizontal distance of the balloon L_3 to the projection C_3, and the tangential -- 1_t, perpendicular to 1_r. In this case we shall have

[formula page 71], (44)

[formula page 71], (45)

[formula page 71], (46)

[formula page 71], (47)

If, as in our case, the direction of the wind is determined

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Velocities and wind directions may be determined also be computations of formulas not using graphical constructions. Such a type of analytical method was developed by V. M. Mikhel, for example.

Computations according to this method consist of the following. For the determination of the wind characterized, for example, by segment C_2C_3, let us separate wind vector l into two components: radial -- l_r according to the direction of the horizontal distance of the balloon L_3 to the projection C_3, and the tangential -- l_t, perpendicular to l_r. In this case we shall have

[formula page 71], (44)

[formula page 71], (45)

[formula page 71], (46)

[formula page 71], (47)

If, as in our case, the direction of the wind is determined while the distance of the projection of the balloon from the point of observation is increasing then the direction will be characterized by angle α, i.e. the azimuth of point C_1 in relation to point C_3. The magnitude of d is determined with the aid of the formula

[formula page 71] (48)

The full velocity of the wind may be found by using the expression convenient for computations with a logarithmic slide rule:

[formula page 71], (49)

where $(t_3 - t_2)$ is the interval of time between readings for the positions of the projections of C_2 and C_3.

It is not difficult to see that the values ℓ_r and ℓ_t are determined with the values of horizontal distances L_2 and L_3 and azimuths α_2, and α_3.

The solution of the problem of determining the velocities and directions of the wind by the stated method has four variants depending on whether the projection of the pilot balloon approaches or recedes from the point of observation and how the azimuth of the balloon changes.

In the practice of processing pilot balloon observations graphical methods are generally used. The determination of the wind by these methods is simpler and more rapid.

No 24. Processing of Pilot Balloon Observations on a Radial Grid.

A radial grid serves for the graphical processing of pilot balloon observations. It represents a diagram on which two systems of straight lines (Figure 33) are plotted.

From the center of the diagram, taken as the point of observation, rays are drawn through each 1 degree. The markings of the angles formed by the rays are designated in accordance with the direction of azimuth readings; whereupon the ray situated along the vertical of the diagram is designated 0 degrees above and 180 degrees below. In this manner the line 0 -- 180 degrees represents the meridian of the point of observation.

The second system of straight lines represents a series of lines parallel to diameter 0 -- 180 degrees, on a distance of four millimeters from each other.

Processing according to radial grid consists of:

(1) the graphical construction of the projection of the path of the pilot balloon according to some scale;

(2) the determination according to this projection of the velocities and directions of the wind.

In order to obtain the horizontal distance of the pilot balloon on the diagram, the construction of a pilot balloon triangle according to altitude and the vertical angle, whose values are known for each reading, is used. The positions of the projections are obtained by plotting the distance from the center found in a direction of the azimuth.

[diagram page 72]

Figure 33. Construction of the projection of the path of the pilot balloon on a radial grid.

Taking the distance between the vertical lines as corresponding to the vertical velocity of the pilot balloon we may represent the altitude of the pilot balloon/minutes after its release by the segment OP which connects the center of the diagram and the n vertical line according to the horizontal. In such a construction the horizontal distance will represent the second side of the pilot balloon triangle OPC.

In order to find it the following is done. Placing one leg of the dividers at point P on the intersection of the horizontal line with the n vertical line, the second leg is moved upward to the intersection of the given vertical line with that ray which corresponds to the reading of the vertical circle after n minutes. It is not difficult to see that the opening of dividers PC will represent on the adopted scale, the second side of the pilot balloon triangle, i.e. the horizontal distance of the balloon.

Having measured it off from the center of the diagram corresponding to the reading of the horizontal circle we shall obtain the position of the projection of the pilot ballon C_n after n minutes.

In this manner all the projections for each reading beginning with the moment of release are plotted on a diagram. As a result a representation of the projection of the path of the pilot balloon $OC_1C_2C_3$... is obtained.

If the projections are situated too close to one another, as ~~this~~ happens in the first minutes of observation, then the scale is increased two to four times and the altitude of the balloon is taken as double or four times the number of divisions between the verticals. In long observations or strong winds the projections may not fit on the diagram; the scale should then be decreased.

Inasmuch as the construction of the projections is made from the calculation that the distance between the verticals, equal to 4 millimeters corresponds to the value of the vertical velocity of the pilot balloon, then it follows that in the determination of the velocity of the wind for various vertical velocities of the pilot balloon the corresponding scales must be used.

For example, if the vertical velocity is equal to 150 meters per minute or 2.5 meters per second then for the determination of the wind we shall obtain the scale of the ruler by assuming that a segment of 4 millimeters represents a velocity of 2.5 meters per second, from which 1 meter per second will correspond to a segment of 1.6 millimeters. Consequently, the scale ruler for a vertical velocity of 150 meters per minute must have divisions equal to 1.6 millimeters. For other vertical velocities the scale is computed analogically.

A so-called meter-second ruler, with scales for the determination of wind over a range of vertical velocities from 150 to 200 meters per minute is used for convenience. On this ruler vertical velocities are shown along the ordinate and divisions giving the velocity of the wind in meters per second, corresponding to the vertical velocities, are shown along the abscissa.

The measurement of the wind velocity is made by placing the scale ruler corresponding to the vertical velocity on the segment between projections [of the position of the balloon.] The number of graduations included gives the velocity of the wind in meters per second.

In case of an increase in the scale while plotting the projection the value obtained for the velocity is diminished proportionately and, inversely, in case of a decrease in the scale it is increased.

A protractor serves for the determination of the direction of the wind.

The protractor is placed on the segment between projections in such a manner that its center coincides with the beginning of the segment and the diameter with the segment. The graduation on the protractor found opposite the radius of the protractor, directed northward, gives the required wind direction.

No 25. Processing of Pilot Balloon Observations by Molchanov's Circle

The method of processing with the aid of Molchanov's circle has found the widest application in pilot balloon observations.

Similar to processing on the radial grid, Molchanov's circle serves for the construction of a projection of the path of the pilot balloon on some scale, according to the horizontal distance of the balloon and its azimuth.

Molchanov's circle consists of three parts (Figure 34): (1) a wooden plane table with a pasted-on diagram; (2) a movable celluloid disk rotating around the center; (3) a movable celluloid ruler.

The main part of the circle is the celluloid disk with divisions from 0 to 360 degrees plotted thereon. The center of the disk represents the site of observation, and for the plotting of the projection, distances to projections at given azimuths utilizing the degree graduations of the disk are plotted from the center. For the determination of the distance to the projection, the diagram of the plane table and the movable ruler are used.

In the right portion of the diagram divisions corresponding to values of vertical angles from 0 to 90 degrees on a double scale as well as the family of curves constructed according to the equation are drawn.

[formula page 74]

Each of the curves of the family corresponds, on the assumed scale, to the horizontal distance of the pilot balloon (to the distances to the projection) for a definite altitude at various values of the vertical angle. For example, the curve designated by the numeral 10 corresponds to the distances to the projection of the balloon from the center computed according to different sizes of vertical angles for an altitude of 1000 meters, the curve designated by the numeral 20 gives the distances to the projection for an altitude of 2000 meters, and so forth. Consequently, if the movable ruler be placed so that its edge passes through the center and the angular division of the diagram corresponding to the reading of the vertical circle, the distance from the center to the intersection of the edge of the ruler with the curve corresponding to the altitude of the balloon would give the distance to the projection.

The curves of the distances to the projections and the grid drawn on the left portion of the diagram are both on a scale where one division of the grid represents 60 meters.

The plotting of the projection on Molchanov's circle is done in the following order:

(1) the edge of the ruler passing through the center of the circle is placed on the division of the diagram corresponding to the corrected reading of the vertical circle;

(2) maintaining the position of the ruler the division of the movable disk equal to the reading of the horizontal circle is brought to the edge of the ruler established by the vertical angle;

(3) the point of intersection of the edge of the ruler with the curve for the distance to the projection corresponding to the

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altitude of the balloon at the moment of reading is found. The point found is marked in ink and the time of reading in minutes is noted.

In this manner the projections for all readings beginning with the moment of release are plotted. It is evident that the positions of the projections are plotted both corresponding to their distances from the point of observation (using the family of curves) and their azimuths, because these distances are marked off on the movable disk in accordance with the reading of the horizontal circle.

In the event an increase in the scale is needed, for example, during the first moments of observation, the altitudes of the balloon are taken two to four times greater than the actual. A need for diminishing the scale calls for a proportionate decrease in the altitude.

The determination of the velocity and direction of the wind is made by the measurement of the segments between projections and the determination of the direction of the segments. For this the segments between projections are brought into a position parallel to the lines of the grid by the rotation of the movable disk. Then the direction of the wind in degrees is read by that division of the movable disk opposite which the diameter of the diagram parallel to the segment is found. The reading is made according to that end of the diameter which is directed toward the preceding projection (from which the balloon moves).

The velocity of the wind is determined by the number of squares of the grid included in the segment of the given portion between projections. Actually, if the projections are plotted every minute on a normal scale, the velocity of the wind will be equal to 60n meters per minute or n meters per second, where n is the number of squares embraced.

A change in the scale in the plotting of the projections is taken into consideration in the determination of wind in the same way as in processing with a radial grid.

It should be noted that the computation of altitudes of the pilot balloon for all times corresponding to the projections is a preliminary condition for plotting the projections on Molchanov's circle.

The velocities and directions of the wind obtained refer to the levels located in the center of each layer, whose altitude is found as a subtotal:

[formula page 75]

where H_n is the altitude of the balloon at the beginning of a given time interval, and $H_n + 1$, the altitude at the end of this interval.

The velocity and direction of the wind at standard altitudes are computed by means of interpolation from the data for the centers of the layers.

In Tables 7 and 8 examples of notations in the pilot balloon observation log and the results of their processing are shown.

After the stated initial processing of pilot balloon observations, a telegram is composed which in a coded form gives the results of the determination of the velocity and direction of the wind at various altitudes.

No 26. Processing of Pilot Balloon Observations Made From A Moving Ship

In the processing of pilot balloon observations from a moving ship it is necessary to take into account the following peculiarities: the change in the position of the place of observation and the method of orienting the theodolite.

The change in the place of observation is determined by the speed and direction of motion of the ship. The speed of the ship is measured in knots (one knot is equal to one mile per hour, or 1.83 kilometers per hour). The direction of motion is determined by the course of the ship, i.e. by the angle formed by the longitudinal axis of the ship and the direction to north.

On the method of orientation of the theodolite depends the determination of the azimuth of the pilot balloon.

In observations from moving ships the orientation of the theodolite may be done in various ways. The theodolite may be oriented according to the meridian, as is usual. In this case, in directing the telescope along the diametral plane of the ship (Figure 35) that division of the horizontal circle equal to the course of the ship k is placed opposite the zero mark of the vernier. Then the readings of the horizontal circle will correspond to the azimuths to the pilot balloon.

In a variable course or drifting a more convenient orientation is the one where the horizontal circle is oriented so that when directing the telescope parallel to the longitudinal axis of the ship the reading on the circle will be equal to zero. Then the azimuth to the pilot balloon will be determined by the sum $K + \varphi$, where φ is the reading according to the horizontal cirlce, i.e.

[formula page 78]

Let the pilot balloon be released at some instant when the ship is found at point O (Figure 36).

At successive times of readings the angular coordinates of the balloon are determined when the ship is at points O_1, O_2, O_3, O_4... The positions of these points, as we have seen, depend on the course and speed of the ship. If the broken line O $C_1C_2C_3C_4$ represents the horizontal projection of the path of the pilot balloon, then, in case of a stationary ship we would have obtained it according to the projections of the pilot balloon at successive times, measuring off the distances to the projections according to azimuth, as is done in the processing of observations from the ground. However, in the case of a moving ship, as is seen from Figure 36, the positions of those same projections are obtained by means of horizontal distances and azimuths differing from thos which are obtained in the case of a stationary point of observation. Under the conditions of a moving ship we can use data determining the distances to projections O_1C_1, O_2C_2, O_3C_3... and the azimuths $\alpha_1, \alpha_2, \alpha_3$ (It is not difficult to see that without taking into account the displacement of the ship we would have obtained a distorted representation of the projection of the path of the pilot balloon expressed by points O, C'_1, C'_2, C'_3...)

[diagram page 79]

Figure 35. Diagram of the orientation of the theodolite on a ship.

[diagram page 79]

Figure 36. Construction of the projection of the path of the pilot balloon in observations from a moving ship.

It is assumed that in the processing of observations the speed and the course of the ship are known.

A special table gives a conversion of speeds expressed in miles to the number of squares of the Molchanov circle for various numbers of minutes.

Having placed the disk division corresponding to the course of the ship opposite one of the diameters of the diagram the points of position of the ship are marked. For this, according to the interval of time from the release to the moment of reading and the speed of the ship, the number of squares corresponding to the distance of the ship from the moment of release is found in the table, and the number of squares found are measured off along the diameter from the center.

Then, according to the data of the altitude and value of the vertical angle obtained from the observation the distances to the projections are found and measured by the number of squares from the center of the disk to the projection.

Then, from each of the plotted points of the positions of the ship the distances to the projections of the balloon according to their azimuths are marked off. For this the divisions of the disk corresponding to the azimuths are made to coincide with the diameters of the diagrams, and the earlier found distances to the projections from the corresponding points of the positions of the ship are marked off parallel to the diameters.

The projections obtained in this manner, referred to the point of release O, will give a projection of the path of the pilot balloon $OC_1C_2C_3C_4...$, which by the usual method yields the speed and direction of the wind.

In case of a change of course of the ship, or its speed and existing drift, the processing does not change in principle, but the stated conditions must be considered in the determination of the position of the ship.